TASK 6

SECOND YEAR POST-PROJECT EVALUATION REPORT, FALL 2000

KNIGHTS FERRY GRAVEL REPLENISHMENT PROJECT

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Produced for

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EXECUTIVE SUMMARY

Study objectives for Task 6 of the Knights Ferry Gravel Replenishment Project (KFGRP) were to compare the spawning and incubation habitat conditions for fall-run chinook salmon (*Oncorhynchus tshawytscha*) at 18 project sites, seven control sites, and a 1997 California Department of Fish and Game restoration site. Three experimental gravels were used for restoration, two consisted of Stanislaus River rock cleaned with different screen sizes and a third consisted of Tuolumne River rock. Each type of gravel was placed at six of the KFGRP project sites between 4 August and 24 September 1999. Monitoring included periodic surveys to map fall-run chinook salmon redds, measure bed permeability in chinook salmon redds, and measure intragravel dissolved oxygen (D.O.), vertical hydraulic gradient, and apparent velocity in artificial redds between 15 October 2000 and 15 February 2001. The elevation of the streambeds and the bed permeability of the undisturbed gravel were measured in September and November 2000, respectively. Natural redds were excavated in March 2001 to determine the number of entombed alevins. As an index of fine sediment intrusion and upwelling of oxygen-poor groundwater, intragravel and surface water temperatures were monitored at 30-minute intervals beginning 25 October 2000 until the thermographs were retrieved between 5 and 15 February 2001. Rain storms were infrequent and minor and streamflow releases were relatively constant during most of the surveys, whereas the last set of measurements made in early February 2001 followed two rain storms that produced relatively little turbid storm runoff.

The density of redds at the study riffles was significantly correlated with the distance downstream from Goodwin Dam in fall 2000 and so comparisons of redd density between project sites and control sites were based on regressions with distance downstream. The density of redds was greater at all project riffles compared to the control riffles. *F*-tests used to compare the regressions indicated that the differences were statistically significant for comparisons with the Stanislaus and Tuolumne river rock cleaned with a 3/8-inch screen and the control sites, whereas the assumption of the test was violated by unequal variances and therefore the test could not be conducted for the comparison between the project sites with Stanislaus River rock cleaned with a 1/4-inch screen and the control sites.

The redd densities at project riffles with Stanislaus River rock cleaned with a 3/8-inch screen were significantly greater than those with similarly-sized Tuolumne River rock in both fall 1999 and fall 2000. This suggests that chinook salmon in the Stanislaus River tend to select spawning sites with Stanislaus River rock because the gravel's odor matches the odor of the gravel where they incubated as eggs and reared as juveniles. Compared to fall 1999, the densities of redds in fall 2000 increased at the sites with Stanislaus River and Tuolumne River rock cleaned with a 3/8-inch screen relative to the densities at the control sites. This suggests that the restoration gravel rapidly "seasoned" during the first year, presumably as the odor of the Tuolumne River rock diminished and as native fine sediments intruded into the riffles which provided a lubricant that facilitated redd construction.

The elevation of the natural riffle's crest as measured under pre-project conditions was not correlated with downwelling rates or the apparent velocity in artificial redds, or the density of chinook salmon redds in the restoration gravel. Vertical hydraulic gradient (VHG), which is the measurement of downwelling rate used in this study, was near zero at all artificial redds in both project riffles and control riffles, regardless of the elevation of the riffle's crest. These results suggest that chinook salmon do not differentiate between restoration sites where gravel has been

added to extensively mined channels, naturally flat channels, or the preferred natural sites at the tails of pools.

Unlike the fall 1999 studies, the intragravel D.O. concentrations in artificial redds were not significantly different between the project and control sites in December 2000, when the eggs begin to hatch, or in early February 2001, after most of the eggs have hatched. The D.O. concentrations were usually greater than 8.0 ppm at almost every artificial redd, which is probably adequate for high egg survival rates.

Three indices of intragravel flow, including permeability in chinook salmon redds, apparent velocity in artificial redds, and deviations in intragravel water temperatures from surface water temperatures that indicate upwelling of oxygen-poor groundwater, all indicated that conditions for egg incubation were better in project sites than in control sites. However, comparison of side-by side measurements of apparent velocity and permeability in artificial redds indicate that the permeability measurements are unreliable. In addition, the apparent velocity measurements taken prior to the late October pulse flow suggest that intragravel flow rates in redds constructed after the pulse flow would be sufficiently high, mean of 6 feet/hour, to support high rates of egg survival at both project and control sites at least until high flows and turbid storm runoff occurred in late January. Furthermore, the deviations in intragravel water temperatures primarily occurred in the downstream sites where few salmon spawn. Therefore, chinook salmon were able to sufficiently clean the substrate during redd construction and provide suitable conditions for egg incubation in both project and control sites during fall 2000. However, fall 2000 was a relatively dry year with little turbid storm runoff through January 2001, whereas egg mortality is probably high during normal and wet years when turbid storm runoff can be considerable. Previous studies suggest that high rates of turbid storm runoff can substantially reduce intragravel D.O. concentrations in redds in the Stanislaus River and laboratory studies suggest that salmonid eggs can be coated with a suffocating layer of clay-sized particles that greatly impairs their ability to absorb oxygen. Further evaluations are needed to determine whether incubation conditions would be substantially better in restoration sites with accumulated fine sediment than in control sites following large increases in flow from turbid storm runoff.

Relatively high rates of alevin entombment were observed in superimposed redds but not non-superimposed redds in both project and control sites. Redd superimposition destroyed or thoroughly disturbed 24% of the artificial redds constructed in fall 2000 which would have killed most or all of the eggs and buried another 23% of the artificial redds with gravel that would entomb some or all of the alevins. Redd superimposition was commonly observed in the seven-mile-long reach in the Stanislaus River between Goodwin Dam and Willms Pond. It is likely that the gravel and gold mining that occurred in the active channel of the Stanislaus River substantially reduced the availability of spawning habitat and thereby caused high rates of redd superimposition by crowding the spawners. The 13,000 tons of gravel added by this project has replaced only a small fraction of the gravel extracted by the miners.

A bed mobility analysis for some of the KFGRP project riffles suggests that flows of 5,000 to 8,000 cfs are necessary to mobilize the median diameter of the channel bed material. During spring 2000, flow releases from Goodwin Dam ranged between 3,000 and 3,500 cfs for about 10 days. As a result, gravel movement primarily occurred at only four of the 18 project riffles where large instream structures, such as large boulders, bridge pillars, large trees, and highly vegetated mid channel gravel bars, caused localized areas of scour. Further fluvial geomorphic evaluations are needed after flows have exceeded 5,000 cfs.

INTRODUCTION

This report presents the results of Task 6, the second year of post-project spawning habitat studies in the lower Stanislaus River conducted in fall 2000 for the Knights Ferry Gravel Replenishment Project (KFGRP). The study objectives were to compare the spawning and incubation habitat conditions for fall-run chinook salmon (*Oncorhynchus tshawytscha*) at 18 project sites, seven control sites, and a California Department of Fish and Game (DFG) project site where gravel was added in 1997 in the upper Goodwin Canyon. A total of 13,000 tons of gravel was added to the 18 KFGRP sites between 5 August and 23 September 1999 (CMC 1999a). All 26 study sites occur between the DFG upper Goodwin Canyon site (RM 58) and Oakdale (RM 40, Figure 1).

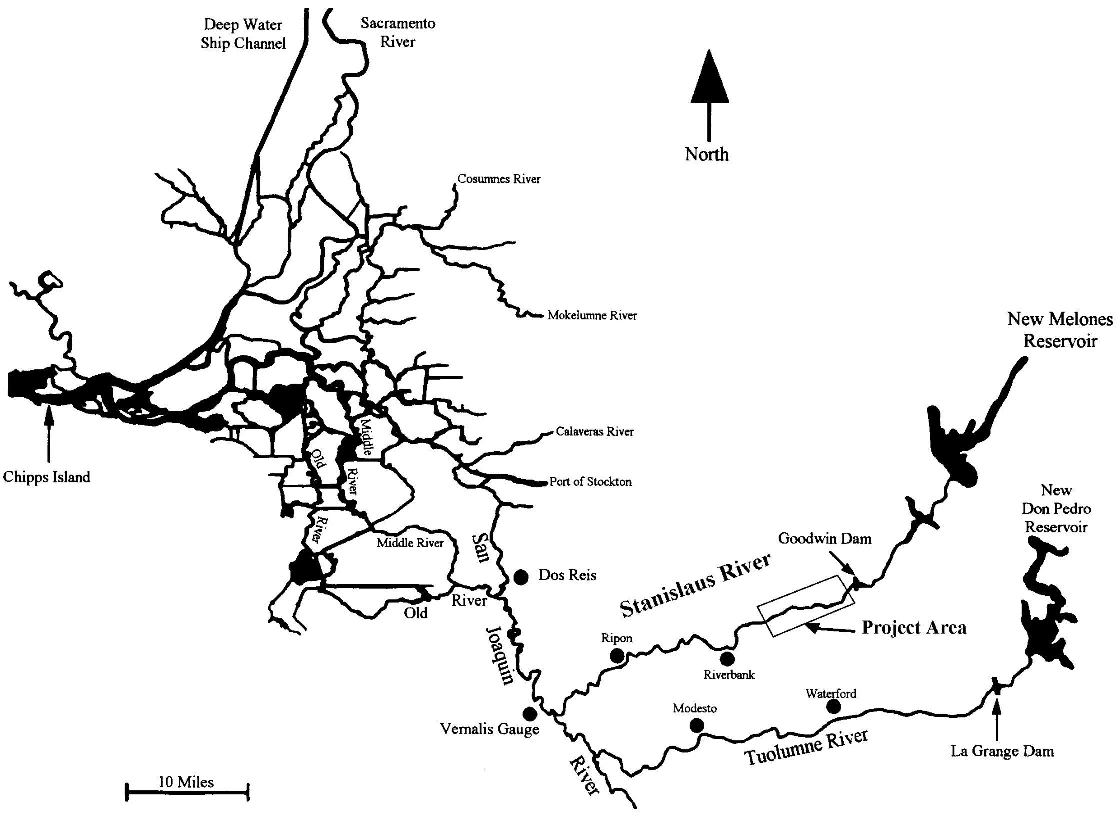

Figure 1. Map of the Sacramento-San Joaquin Delta showing the Stanislaus River, Goodwin Dam, and the project area.

Justification for the KFGRP was based on several studies. A Department of Water Resources (DWR 1994) study of 22 riffles between Goodwin Dam and Riverbank indicated that 45% of the riffles sampled had excessive levels of fines in substrate samples collected from the upper sections of the riffles where the salmon prefer to spawn. Redd surveys in 1994 and 1995 (Mesick 2001a) indicate that most chinook salmon spawned in the 12-mile reach between

Goodwin Dam and the Orange Blossom Bridge (RM 46.9). These surveys also indicate that 73% of the salmon spawned upstream of the riffles' crests where the streambed sloped upwards (e.g., the tail of a pool). At 10 natural riffles between Two-Mile Bar (RM 56.6) and Oakdale where redd densities were relatively high in 1994 and 1995, intragravel dissolved oxygen (D.O.) levels in artificial redds were probably suboptimal between November 1995 and February 1996 due to the combined effects of decaying Asian clams (*Corbicula fuminea*) that were buried during redd construction, excessive fines, and the inflow of oxygen-poor groundwater, particularly after intensive rain storms (Mesick 2001a). Intragravel D.O. levels were less than 5 ppm at 15% of the piezometers in artificial redds and less than 8 ppm at 31% of the piezometer sites during five surveys in November and December 1995. Immediately after five intensive rain storms in early February 1996, D.O. levels declined to less than 5 ppm at 42% of the sites and to less than 8 ppm at 62% of the sites. Elevated intragravel water temperatures, an indicator of groundwater inflow, occurred at many of the sites where D.O. levels declined after the intensive rain storms. Although the survival of salmonid eggs has been extensively studied, it is not possible to accurately estimate egg survival based on measurements of substrate fines, D.O., or intragravel flow rates (Chapman 1988). A literature review of salmonid egg survival studies is presented in CMC (2001b).

The poor quality of spawning habitat in the Stanislaus River has resulted from the blockage of coarse sediment supply from the upper watershed by dams and from instream gravel mining downstream of Goodwin Dam from about 1940 to the 1970s (Mesick 2001b). The loss of upstream gravel recruitment has contributed to the armoring of riffles in Goodwin Canyon and the one-mile section immediately downstream of the Knights Ferry County Bridge. Downstream from there, many riffles were completely excavated by in-river gravel mining. Kondolf et al. (2001) estimated that 1,031,800 yd^3 of gravel was extracted from the active channel between Goodwin Dam and Oakdale from 1949 to 1999. Surveys conducted by DFG (1972) in the 1960s suggest that about 55% of the channel between the Knights Ferry County Bridge and the Orange Blossom Bridge was repeatedly mined. Furthermore, a comparison between the DFG surveys conducted in the 1960s and surveys conducted in 1995 and 1996 (Mesick 2001a) suggest that the few riffles that were left untouched in the dredged reaches have since become armored and shortened (Mesick 2001b).

The mean escapement of fall-run chinook salmon to the Stanislaus River declined from 15,000 fish from 1947 to 1954 to 4,700 fish from 1955 to 1989, and then to 737 fish from 1990 to 1998 (Mesick 2001b). While it is likely that water development and Delta exports contributed to this decline, the in-river gravel mining between 1940 and the 1970s probably was another contributing factor (Mesick 2001b). A stock-recruitment analysis for the Stanislaus River chinook salmon population from 1948 to 1995 suggests that recruitment initially increases as stock increases until stock reaches about 2,500 fish; thereafter recruitment remains constant as stock increases (Mesick 2001b). This suggests that the habitat in the Stanislaus River can support the progeny of only 1,250 pairs of adult salmon.

To evaluate whether adding clean gravel to the streambed of the Stanislaus River improves spawning and incubation habitat, studies were designed to test ten hypotheses identified in the KFGRP Ecological Monitoring Plan (CMC 1999b). There are two hypotheses on improving spawning habitat:

Hypothesis I-A: The density of fall-run chinook salmon redds will be higher in unconsolidated gravel in the project riffles than in the cemented gravel in the control riffles.

Hypothesis I-B: The higher the elevation of a riffle's crest, the greater will be the rate of surface water downwelling that presumably helps attract spawners.

There are three hypotheses on improving incubation habitat:

Hypothesis II-A: Adding gravel without fines to the streambed increases intragravel flow in redds.

Hypothesis II-B: Higher gradients of the streambed upstream of the hydraulic control at the riffle's crest result in higher rates of surface water downwelling that presumably increases intragravel dissolved oxygen concentrations.

Hypothesis II-C: The low percentage of fines in the project riffles will result in high intragravel D.O. concentrations relative to those at the control riffles, where the concentration of fines is high.

Other hypotheses were developed to improve the techniques required to restore spawning habitat. In summer 1994, DFG and DWR reconstructed two riffles, R27 and R28, in the Stanislaus River near the Horseshoe Road Recreation Area (RM 50.4 and RM 50.9) and another riffle just upstream of the Orange Blossom Bridge (RM 47.4) that were used by relatively few spawning chinook salmon. These three riffles were reconstructed by excavating the channel bed to a depth of 1.5 feet to remove gravel and silt, and replacing the excavated material with washed gravel, sized from 0.5 to 4 inches (Kondolf et al. 1996). The washed gravel was imported from the Blasingame Quarry near the Merced River and about 60% of the rock had sharp edges (Mesick 2001a). Only about 20% of natural gravel from the Stanislaus River had sharp edges (Mesick 2001a). Rock weirs were constructed at the upstream and downstream boundaries of each site to achieve the "necessary grade" of 0.2% to 0.5% and to retain the imported gravel during high flows. Redd surveys at these two riffles (R27 and R28) at the Horseshoe Road Recreation Area indicated that few salmon spawned in the added gravel through fall 1997, whereas redds were observed in natural gravel adjacent to the added gravel (Mesick 2001a). After a 15-foot-long, two-foot high berm of natural gravel had been deposited across the crest of Riffle R27 in spring 1997, 16 redds were observed in the gravel berm whereas only one redd was observed in the restoration gravel in fall 1997.

In 1996 and 1997, DFG added about 2,000 tons of gravel obtained near the Stanislaus River to several sites in upper Goodwin Canyon where gravel was scarce. The added gravel contained very little angular rock, and ranged from 0.35 to 5 inches in diameter. It was added to the undisturbed streambed in pools and in bars across shallow areas. Many salmon spawned in this new gravel in the first season (Mesick 2001a).

The following three hypotheses were developed to test why the salmon utilize some restoration sites but not others:

> Hypothesis III-A: Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from another watershed.
>
> Hypothesis III-B: Restoration gravel between 3/8 inch and 5 inches will produce higher gravel permeabilities than will gravel between 1/4 inch and 5 inches.
>
> Hypothesis III-C: Restoration gravel between 1/4 inch and 5 inches will attract more spawners than will gravel between 3/8 inch and 5 inches.

The following two hypotheses were developed to test the effects of the streambed configuration on the useful life of the project.

> Hypothesis IV-A: During high flows, high-crested riffles retain more gravel than moderate-crested riffles, which retain more gravel than low-crested riffles.
>
> Hypothesis IV-B: Project riffles in mined channels will lose gravel at a faster rate than will project riffles adjacent to functional floodplains.

METHODS

Monitoring at the 26 study riffles between Goodwin Dam and Oakdale included periodic surveys to map fall-run chinook salmon redds, measure bed permeability in chinook salmon redds, and measure intragravel dissolved oxygen (D.O.), vertical hydraulic gradient, and apparent velocity in artificial redds between 15 October 2000 and 15 February 2001. The elevation of the streambeds and the bed permeability of the undisturbed gravel were also measured in September and November 2000, respectively. As an index of fine sediment intrusion and upwelling of oxygen-poor groundwater, intragravel and surface water temperatures were monitored at 30-minute intervals beginning 25 October 2000 until the thermographs were retrieved between 5 and 15 February 2001. Rain storms were infrequent and minor and streamflow releases were relatively constant during most of the surveys, whereas the first set of measurements was made just prior to a 1,100 cfs pulse flow and the last set was made in early February 2001 following two rain storms that produced no more than 64-cfs of turbid storm runoff at the Orange Blossom Bridge. Redd counts and permeability measurements at redds and undisturbed gravel were made at four new control riffles on 17 December 2000. Natural redds were excavated at two riffles on 14 March 2001 to determine the number of entombed alevins.

During monitoring from mid October 2000 to early February 2001, streamflow releases from Goodwin Dam were periodically changed. Flows were initially held constant at 300 cfs until 17 October 2000, when a pulse flow up to 1,100 cfs was released until 22 October. After the pulse flow, flows were held constant at 375 cfs until 22 December. Then flows were reduced to 350 cfs until 28 December 2000, when flows were reduced to 325 cfs until 19 January 2001. Between 19 January and 14 February 2001, releases were maintained at 300 cfs. Flows were reduced again to 270 cfs for the last day of monitoring on 15 February.

STUDY AREA

The spawning reach for fall-run chinook salmon in the Stanislaus River is about 25.5 miles long and extends from Goodwin Dam, which is impassible for salmon, downstream to the town of Riverbank. During fall 1995 surveys, the riffles in the spawning reach were numbered and their locations marked on USGS quadrangles. In the 4.2 mile high-gradient canyon between Goodwin Dam and the Knights Ferry County Bridge, four riffles (TMA, TM1, TM2, and TM3) were identified near the Two-Mile Bar Recreation Area (RM 57). Downstream of the Knights Ferry County Bridge toward Riverbank, 106 riffles were marked during 1,500 cfs pulse flow surveys with a numbered 3-inch orange square that was nailed to either a tree or woody debris near the upstream boundary of each riffle. The riffle immediately upstream of the Knights Ferry County Bridge was identified as "R1." The other riffles were sequentially numbered in a downstream direction from there. During subsequent redd surveys conducted when flows were reduced to about 300 cfs, an additional 26 riffles and four small gravel berms were identified. These areas were identified by adding a letter to the upstream riffle's number. For example, an unmarked spawning area downstream of Riffle R2 was called Riffle R2A.

From the 140 riffles and spawning areas identified in the spawning reach in 1995, 18 sites for gravel addition and 7 control riffles were selected for the KFGRP as shown on USGS quadrangle maps in Appendix 1. The 18 project sites were classified into three categories based on the height of the riffle's crest (Table 1 in Appendix 2). However, since the proposal was prepared during the summer of 1997, gravel movement occurred at several sites that changed the height of the riffle's crest. Besides the change in the riffle's crest, the original classifications were based on elevations measured on a single transect along the length of the riffle, which are not as useful as the contour maps made in August 1999 that show the topography of the entire streambed. Based on the August 1999 data, riffles R10, R14, and R19A were reclassified from moderate-crested riffles to low-crested riffles, and riffles R13, R20, and R43 were reclassified from low-crested riffles to moderate-crested riffles. Riffle R15 was reclassified from a high-crested riffle to a moderate-crested riffle. Spawner use and incubation conditions were previously monitored at KFGRP riffles TM1, R10, and R27 in fall 1995 (CMC et al. 1996) and at KFGRP riffles R10, R14, R29, R43, R58, and R78 in fall 1996 (CMC 1997).

Four new control riffles were selected to provide additional permeability measurements at redds and undisturbed gravel. These new riffles include Riffle R2, which is upstream of the heavy turbid storm runoff, Riffle R11, which is between two small gravel mine pits, Riffle R26, which is in an unmined reach directly downstream from Willms Pond, and Riffle R44, which usually receives highly turbid storm runoff as do all riffles downstream of the Orange Blossom Bridge. The locations of these riffles are shown in Appendix 1.

SPAWNER USE

Redds were identified as oval disturbances in the substrate. They typically have a shallow pit or depression in the upstream half of the disturbed area and a mound of gravel at the downstream half of the disturbance called a tailspill. Most redds were approximately five feet wide by 10 feet long. After it appeared that a redd had been completed, a numbered 2-ounce lead sinker with orange flagging was placed in some of the redd's pits for identification. Marking was necessary because algal growth and sediment movement progressively made it more difficult to distinguish some of the redds within 10 to 20 days after the female stopped tending the redd.

Redd locations were mapped at each riffle by means of reference to either 2-foot long reinforcing bars driven into the ground or nails driven into trees on both sides of the river. A transect was established at each riffle by running a tape measure from the pin on the left bank (facing downstream) to the one on the right bank during all surveys. A second tape measure was then run from the redd to the transect so that both tape measures were perpendicular to each other. The distance in feet from the pin on the left bank along the transect to the tape measure from the redd was recorded as the station. The distance in feet from the redd to the transect and the direction (upstream or downstream) from the transect were also recorded. An x-y plot of the redd locations at each riffle was used during each survey to help identify old and new redds. The redd coordinates were plotted on a contour map of each site made from streambed elevation measurements made in September 2000. The transects shown on the contour maps were used to map redds and measure streambed elevations.

At the four new control riffles, R2, R11, R26, and R44, redds were counted on 17 December 2000. It is likely that the number counted is less than the actual number of redds constructed at each site, because superimposed redds would not have been detected. Therefore, redd counts from these riffles are used only as a general index of spawning and are not included in statistical analyses of the KFGRP sites.

STREAMBED ELEVATION AND CONTOUR MAPPING

Relative elevations were measured between 18 and 30 September 2000 in a 15- to 20-foot grid pattern, at major changes in grade along the streambank and channel bottom, and along transects established in November 1998 and September 1999 with a Nikon DTM-310 total station. Elevations of the tops of two to four 18-inch long, 3/4-inch diameter steel rods driven into the ground in August and September 1999 were measured at each site as reference points. These reference points, which are called backsights in the maps in Appendix 1, permitted comparisons of data sets collected at different total station locations or different years. At some sites it was not possible to survey the entire riffle from one location due to the dense vegetation along the streambanks. At these sites, the total station was set at two locations, usually on opposite sides of the river.

The Nikon total station has an angle accuracy of five seconds, which provides elevation measurements accurate to within 0.03 inches at a distance of 100 feet. The elevation data were collected as X, Y, Z coordinates that were stored electronically within the total station and then downloaded to a laptop computer. A software program called “Transit” was then used to convert the data into AutoCAD DXF format files. The DXF files were then imported into a software program called Terrain Version 3.127 developed by Softree Technical Systems Inc. to generate the contour maps in one-foot intervals. The contour maps show the location of the transects established in November 1998 and a few additional transects established at project sites in late August and September 1999 that were needed to provide measurements over the newly placed gravel (Appendix 3).

All elevations measured under pre-project and post-project conditions were adjusted to correspond to the height of the measurements of the backsights recorded in December 1999. Therefore, the bed and water surface elevations of the transects presented graphically in Appendix 4 match those in the contour maps in Appendix 3.

To determine the volume of gravel mobilized from the project sites between December 1999 and September 2000, the Terrain models for each site were compared using the Terrain software. First, the x,y, and z data for each model were adjusted so that the coordinates for the backsights for the December 1999 model matched those for the September 2000 model. Then the Terrain software was used to estimate the volume of material in the September 2000 model that is either above (fill) or below (cut) the surface of the December 1999 model. The volume of gravel mobilized was computed by subtracting the volume of fill from the volume of cut.

SUBSTRATE PERMEABILITY

Permeability was measured at a depths of 12 inches during three surveys between 11 November 2000 and 15 February 2001. The initial survey conducted between 11 and 17 November 2000 measured permeabilities in undisturbed gravel near each artificial redd and at the presumed egg pocket of 30 salmon redds, some of which were known to be less than 10 days old. The second survey conducted between 25 December 2000 and 6 January 2001 measured permeabilities at

103 salmon redds in the KFGRP sites, and 17 salmon redds and 17 undisturbed gravel sites in the four new control riffles, R2, R11, R26, and R44. The redds at the KFGRP sites were completed before 24 November 2000, which indicates that they were between 30 and 70 days old, whereas the age of the redds at the new control sites was unknown. The third survey conducted between 5 and 15 February measured permeabilities approximately 3 inches upstream from the apparent velocity wells. During this survey, the standpipe used for the permeability measurement was driven into the substrate after apparent velocity had been measured.

Substrate permeability depends on the composition and degree of packing of the gravel and the viscosity of the water (as related to water temperature) and reflects "the ease with which water can pass through it" (Pollard 1955). Measurements were made with standpipes that were similar to the Terhune Mark IV permeability standpipe (Terhune 1958). Two standpipes were constructed for these measurements, one 4.5 feet long and the other 5.5 feet long. They were made of 1.12-inch (28 mm) inside diameter schedule-40 stainless steel pipe with a 3-inch long solid stainless steel driving tip at one end. Above the driving tip, there was a three-inch long cavity to store sand that entered the pipe during sampling. Immediately above the cavity, there was a three-inch long band of perforations around the standpipe. The perforations were 0.12 inch (3-mm) diameter holes, spaced 0.75 inches apart in columns of four holes. A 0.08-inch (2-mm) wide groove was cut about 0.08 inches deep along each of the columns to prevent sand grains from plugging the holes. There was a total of 12 rows of holes and every other column was offset by 0.375 inches to stagger the holes. A one-inch thick driving head was inserted into the standpipe when driving it into the streambed. The standpipe was marked with a band of red plastic tape 19.5 inches from the driving tip. When the standpipe was driven into streambed to the red tape, the middle of the band of perforations was 12 inches below the surface of the substrate.

Permeability measurements were made with a homemade pumping device that employed a 12-volt DC battery and a 35 psi diaphragm vacuum pump (Thomas, model #107CDC20-975C) to draw water into a clear cylindrical vacuum chamber, 3.56 inches in diameter and 20 inches long. The device was mounted on a backpack frame. Two 3/8- inch polypropylene hoses were used, one to connect the pump to the vacuum chamber and the other to draw water from the standpipe into the vacuum chamber. A 1/4-inch inside diameter plastic tube and a fiberglass tape with gradations in centimeters was attached to the side of the vacuum chamber to measure the change in height (i.e., volume) of the water drawn into the vacuum chamber. For each one-centimeter change in water height in the chamber, 64.7 ml were drawn into the chamber.

To measure permeability, the pump was switched on and the hose was slowly lowered into the standpipe until a slurping noise was heard indicating that there was contact with the water. A one-inch spacer was then placed on top of the standpipe and a clamp was attached immediately above the spacer to the side of the hose without constricting it. The pump was then switched off, the spacer removed, and the hose lowered until the clamp rested on top of the standpipe. This placed the end of the hose one inch below the water's surface in the standpipe. Then, the pump was switched on and after the water level in the vacuum chamber reached the zero mark, the stopwatch was activated. Usually after 1,294 ml had been collected, the stopwatch was turned off and the duration and volume were recorded. When pumping rates were extremely slow, pumping was continued for at least 40 seconds and then the volume of water pumped and the exact duration were recorded. Water temperature was measured in the standpipe with an Extech electronic thermometer to the nearest 0.1 degrees Celsius to determine a viscosity correction factor.

Permeability was then interpolated from an empirical permeability versus a corrected inflow rate calibration table provided by McBain and Trush (Table 2 in Appendix 2). The calibration table provides conversions up to 110.9 ml/sec for field inflow rates whereas higher rates were measured at the restoration sites and in redds. Conversions were made for readings that exceeded 110.9 ml/sec by increasing the permeability by 500 cm/hr for each 0.1 ml/sec increase in the field inflow rate beyond 110.9 ml/sec. For example, a field inflow rate of 111.0 ml/sec was converted to a permeability of 105,000 cm/hr. After the field inflow rates were converted to a permeability value, the permeability value was standardized to a temperature of 10 degrees Celsius by the viscosity correction factor presented in Barnard and McBain (1994).

The expected survival of chinook salmon eggs was computed using the results of McCuddin's study (1977) which tested the relationship between permeability and the survival to emergence of chinook salmon eggs in laboratory streams. However, these estimates should be viewed with caution as McCuddin simultaneously varied the sand concentration, permeability, and intragravel velocity for each test and so it is not possible to determine whether permeability or the other two factors affected egg survival. A linear regression was tested between the natural log of the permeability of three gravel mixtures with percentages of sediment less than 6.4 mm of 21%, 28%, and 39% and the survival to emergence (STE) of newly fertilized eggs during the first year of study (Figure 2). McCuddin's results for gravel mixtures with the highest permeability levels were not used in this regression analysis because the permeability did not appear to be accurately measured for the mixture without fines and the STE for the mixture with 15% fines was not significantly different from the STE for the mixture with 21% fines. McCuddin's results for his second year of study were not used because he reported that over time, the fine sediments settled in his experiment stream troughs creating a heterogenous gravel mixture that greatly increased the variability among replicates. The adjusted-R^2 for the model of the limited data set between the log of permeability and percent survival of salmon eggs was 0.808. The expected survival of salmon eggs was computed using the following regression model:

$$\text{Percent Survival} = 0.1865 * \text{Ln (Permeability cm/hr)} - 1.0951$$

Permeability estimates that resulted in negative values were truncated at zero and high values were truncated at 77%. The maximum STE of 77% is the average for McCuddin's first year tests with gravel mixtures of 16% and 21% fines.

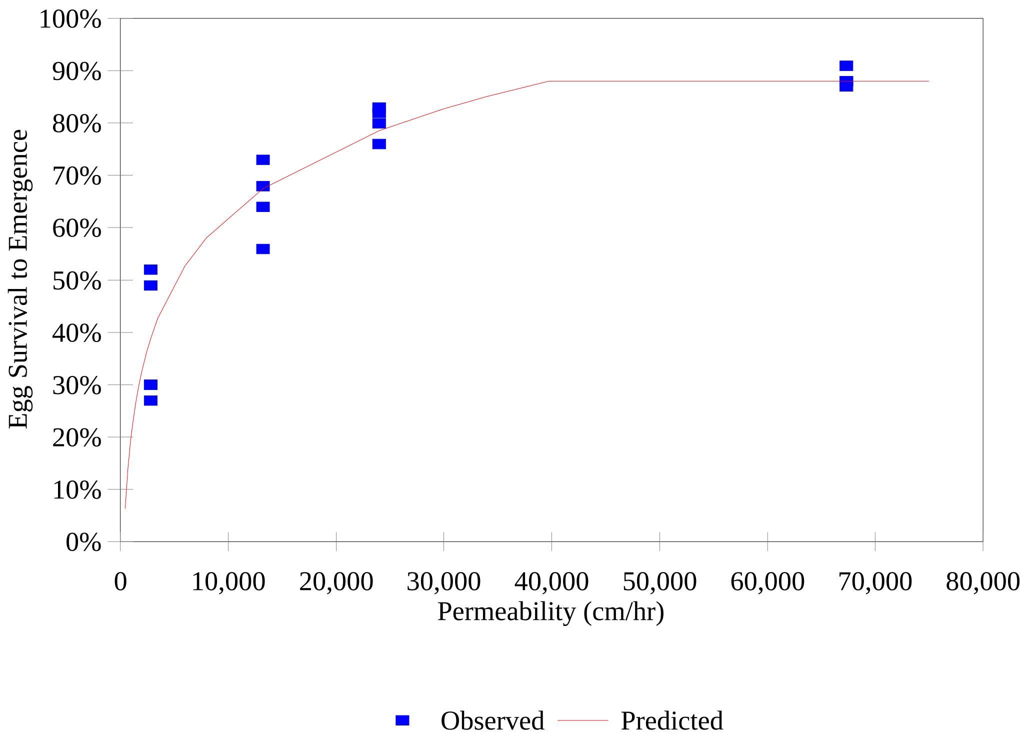

Figure 2. Survival to emergence of chinook salmon eggs relative to gravel permeability based on first-year data from a laboratory stream study by McCuddin (1977). The observed survival to emergence estimates at 67,350 cm/hr correspond to McCuddin's tests with no fine sediment less than 6.4 mm. The solid line indicates the predicted survival to emergence for restoration gravel mixtures based on the equation shown above with the estimates truncated at 88%..

PIEZOMETER DESIGN

Intragravel water samples were collected from piezometers buried in artificial redds approximately 12 inches below the substrate's surface. Four artificial redds with piezometers were constructed at most of the 26 study riffles between 25 September and 13 October 2000 at the locations shown in the contour maps in Appendix 3. Only two piezometers were installed in riffles R5, R12 and R28A and none were installed at riffles DFG2, TMA, TM1, and R43 due to expected high rates of disturbance by salmon constructing redds or vandalism.

Piezometers were 10-inch long, 1/4-inch outside diameter copper tubes, each with one end of the tube pinched nearly closed and eight 0.04-inch diameter holes drilled or punched in the tube near the closed end. The middle of the copper tube was positioned in the center of a 4-inch x 4-inch x 4-inch cement cube that was allowed to harden around the tube to serve as an anchor. A latex additive was added to the cement to maintain its integrity in water. The other end of the copper tubing was attached to a clear polyvinyl chloride (PVC) flexible tube that extended to the surface of the water. The PVC tubing was 1/4-inch inside diameter and had a wall thickness of 1/16-inch.

A 1.25-inch inside diameter PVC pipe was embedded in the piezometer's cement anchor to contain an *Onset StowAway TidbiT* thermograph. The PVC pipe extended 3 to 4 inches from the cement anchor and the thermograph was suspended within the center of the pipe with 15-pound test monofilament line. A PVC cap was placed over the open end of the pipe and twelve 5/16-inch holes were drilled into the pipe and three more holes were drilled into the cap.

Piezometers were installed to simulate sampling in an egg pocket in a natural salmon redd. Pits were dug with a shovel approximately 14-inches deep by 14-inches wide at the bottom. The excavated substrate was piled downstream of the pit to simulate the tailspill formed in a natural redd. After the piezometer and slotted well pipe used to measure apparent velocity were placed in the pit, sediment was pulled into the pit in thin layers from the upstream areas using a hand-held hoe. The blade of the hoe was then fanned over each layer of gravel in the pit to flush most of the fines onto the tailspill. Then the streambed was excavated and "turned-over" with a shovel to a depth of 8 to 10 inches throughout the area approximately 6 feet upstream of the tailspill to simulate the construction of multiple egg pockets. When completed, the piezometer was located at the upstream end of the tailspill which was raised several inches above the undisturbed streambed. An egg pocket would be expected to occur at the piezometer's location in a natural redd (Vronskiy 1972, Hawke 1978). Immediately upstream of the tailspill, there was a two- to four-inch deep depression in the streambed that simulated the pit of a 3-foot wide by 10-foot long natural-looking redd. At some of the artificial redds, the depressions were filled and the tailspill eroded away by natural sediment transport within seven to ten days. This smoothing also occurs at natural redds (Vronskiy 1972, Mesick 2001a).

APPARENT VELOCITY

Apparent velocity is the horizontal vector of interstitial flow and is a function of permeability and hydraulic gradient (Pollard 1955; Freeze and Cherry 1979). It was measured with a KVA Model 40L Geoflo Groundwater Flowmeter inserted into slotted well pipe buried in each artificial redd. The groundwater flowmeter, which was manufactured by K-V Associates, Inc., Mashpee, MA, is a portable self-contained instrument for measuring the direction and rate of horizontal flow of water through permeable soils. Although designed to measure very slow flow rates in soils, Orchard (1988) reported that the older KVA Model 30 could be calibrated for flows between zero and 16.4 ft/hr, which spans the range reported for spawning gravel under natural conditions (CMC 2001a). The Model 40L flowmeter has a 1.75-inch diameter submersible probe that creates a 26.8-second duration pulse of heat of about 500 degrees Fahrenheit and four pairs of opposed thermistors that surround the heat source. Heated water is displaced by the flow of water and the flow rate is proportional to the net difference in temperature between paired thermistors. In an absence of intragravel flow, the heat pulse radiates toward all the thermistors at the same rate and there is no net difference between the opposed pairs of thermistors. When flow occurs, the heat pulse is displaced by the flow toward one side of the probe. The magnitude of flow is proportional to the net difference in temperature between the opposed pairs of thermistors. The digital output of the flowmeter corresponds to the net difference between the opposed pairs of thermistors. One must individually view the digital output for each of the four pairs of thermistors with a rotary channel selector on the flowmeter's control unit. The direction of flow is determined by knowing the polar orientation of the thermistor pair with the highest net difference in temperature and by the sign (negative or positive) of the digital readout. For example, thermistor number 6, which was designated as South by K-V Associates, was always oriented facing into the surface flow (upstream) during field measurements or toward the source of the flow during calibration measurements. If the 1-6 thermistor pair gave the highest measurement (i.e., the highest net difference in temperature) and the measurement was positive, then the intragravel flow was in a downstream direction as expected. However if the 1-6 thermistor pair gave the highest measurement but the measurement was negative, then the intragravel flow was in an upstream direction. If the other pairs of thermistors give the highest measurements, then the intragravel flow was moving perpendicularly to the surface flow.

Measurements were made by inserting the probe into a slotted well screen buried in the artificial redds. The slotted well screen used was a 1.9-inch inside diameter Monoflex (previously Timco Manufacturing Company) schedule-40 PVC pipe with four columns of 0.020-inch screen gauge slots as recommended by K-V Associates (Kerfoot 1988). There were 59 slots per foot of pipe that permitted approximately 40% of the unimpeded flow to pass through the well screen (Kerfoot 1988). The entire well consisted of an 8-inch length of well screen connected to a 6-inch length of solid PVC pipe with a PVC coupler. Another PVC coupler was connected to the other end of the well screen and a 1-foot long, 1/4-inch diameter reinforcing bar was inserted halfway through a hole in the coupler to help keep the well stationary in the streambed. The bottom of the well was not capped to minimize flow through the screen's slots when the probe was inserted into or removed from the well. High rates of flow through the slots due to the movement of the probe would have caused excessive amounts of silt to lodge in the slots and potentially disrupt the distribution of fines surrounding the probe. The well screen and reinforcing bar were placed into the pit of the artificial redd approximately two inches from the piezometer such that one column of slots faced directly upstream. The solid PVC pipe extended above the substrate surface by about 2 inches after the artificial redd was completed. A cap was loosely placed over the exposed pipe to prevent water and gravel from entering the well screen between measurements. The upper portion of the solid PVC pipe and cap were painted to camouflage the pipe.

It was necessary to calibrate the digital readout of flowmeter to determine the rate of flow through the slotted well screen, which is called the apparent yield (K-V Associates). To compute apparent velocity, apparent yield is divided by the porosity of the gravel surrounding the well screen. It was necessary to calibrate the flowmeter for different gravel mixtures because substrate porosity affects the flowmeter readings in two ways. First, if the flow rate is equal for two gravel mixtures, the apparent yield and the meter's readout will be higher in gravel with a high porosity than in gravel with a low porosity. Second, the difference in permeability in the gravel surrounding the well screen compared to the permeability of the well screen and the sensor, which has glass beads and a "fuzzy packer" jacket surrounding the heater and thermistors, affects the apparent yield. If the surrounding gravel is highly permeable, then most of the intragravel flow bypasses the well. However, if the permeability of the surrounding gravel is low, then most of the intragravel flow passes through the well because the well offers the path of least resistance.

The flowmeter was calibrated in an 8-inch diameter PVC flow chamber provided by K-V Associates, Inc. Calibration was conducted by first inserting the slotted well screen into the chamber, which was then packed with one of two gravel mixtures to within 2 inches of the top of the chamber. The tip of the flowmeter's sensor with the thermistors and heater was positioned in the center of the chamber. The chamber was filled with water to just below the surface of the gravel to prevent water from flowing over the surface of the gravel which would have made it impossible to accurately compute the flow rate through the gravel. Between six and eight flow rates up to 20.1 ml/second were created in the chamber with a Fluid Metering, Inc., Lab Pump model QD and Pump Q combination. Flow rates were measured by collecting the outflow from the calibration chamber into a graduated cylinder, which was either 100-ml, 500-ml, or 1,000-ml, depending on the flow rate. The outflow was collected for approximately 20 seconds for the highest flow rates and up to 2 minutes for the lowest flow rates as measured to the nearest 0.1 seconds with a stopwatch. The apparent velocity in the chamber was computed as the pump flow multiplied by a conversion constant of 0.146 for the calibration chamber (K-V Associates) divided by the estimated porosity of each gravel mixture. To maintain water temperatures, the chamber was placed within an insulated cooler which was filled with water of the same temperature as the water in the chamber. Water temperatures were measured inside the well just below the flowmeter's sensor immediately prior to each flow measurement with the same Extech electronic thermometer that was used for field measurements. The Extech electronic thermometer was accurate to within 0.1 degrees Celsius based on comparisons with an ASTM 15 degree Celsius thermometer.

Two mixtures of gravel were tested. One mixture consisted of the Stanislaus River rock washed with a 1/4-inch screen and 5-inch grizzly that was obtained from Riffle R19 in October 2000. This gravel was washed to remove most of the particles smaller than 0.25 inches in diameter and all rocks larger than 2.5 inches were removed. The porosity of a 3,158-ml, dried sample of this mixture was 0.262. The other mixture was created by adding a sufficient amount of fines less than 2-mm in diameter to the gravel from Riffle R19 to produce a concentration of fines less than 2-mm in diameter of 32%. The porosity of a 3,364-ml, dried sample of this mixture was 0.209. It was assumed that these two gravel mixtures represented the range in porosity at all well sites measured in the field. Both gravel mixtures were thoroughly stirred in a tray with a hoe to ensure a homogenous mixture before the gravel was packed into the chamber. The cumulative size distribution curves for these two mixtures and the gravel added to Riffle R19 are shown in Figure 3.

Calibration was also conducted over a range of water temperatures that were encountered in the field. Three water temperatures were tested for each gravel mixture. The three water temperatures tested with the clean gravel mixture (porosity = 0.262) ranged between 8.9 to 9.2 degrees Celsius for seven flow rates tested, 10.0 to 10.3 degrees Celsius for six flow rates tested, and a constant 13.0 degrees Celsius for six flow rates tested. The three water temperatures tested with the silty gravel mixture (porosity = 0.209) ranged between 9.0 and 9.3 degrees Celsius for eight flow rates tested, 10.7 to 11.1 degrees Celsius for six flow rates tested, and a constant 12.7 degrees Celsius for eight flow rates tested.

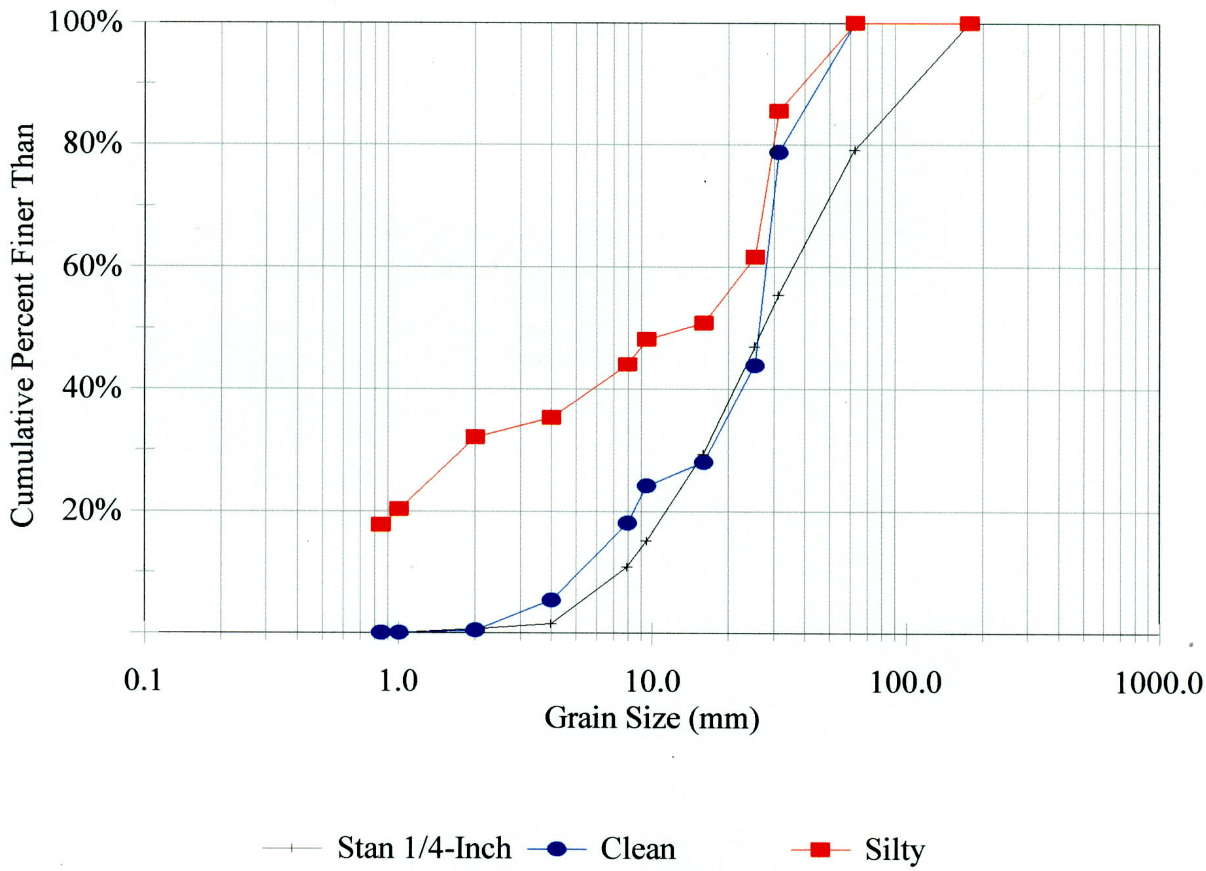

Figure 3. Cumulative size distribution curves for the clean gravel mixture (porosity of 0.262) and the silty gravel mixture (porosity of 0.209) used to calibrate the KVA Model 40L Geoflo Groundwater Flowmeter and the restoration gravel (Stan 1/4-Inch) that was obtained from near the Stanislaus River and washed with a 1/4-inch screen prior to placement in September 1999.

The results of the calibration tests indicate that neither gravel porosity nor water temperature had a substantial effect on flowmeter measurements (Figure 4). For example, for a relatively high flowmeter measurement of 600, the apparent velocity would be estimated at 7.5 ft/hr in the clean gravel mixture and 9.0 ft/hr in the silty gravel mixture at a temperature of about 10 degrees Celsius. The effect of water temperature ranging between 9 and 13 degrees Celsius was even less noticeable. For example, for a relatively high flowmeter measurement of 600, apparent velocity would be estimated at 7.0 ft/hr at 9 degrees Celsius and 7.75 ft/hr at 13 degrees Celsius in the clean gravel mixture. These differences were considered to be inconsequential because the differences declined to low levels for measurements less than 200, which were typical of field conditions in fall 2000. Therefore, apparent velocity was estimated for this study by assuming that the gravel mixtures in all artificial redds were initially quite porous due to the cleaning process during redd construction and that the initial porosity at the redds were equivalent to the clean gravel mixture used for the calibration tests. It was also assumed that as the apparent velocity declined due to fine sediment intrusion in the artificial redds, that the porosity gradually declined to a level that was equivalent to the silty gravel mixture used for calibration tests. The equations presented below were used to compute apparent velocity measured under field conditions at all artificial redds regardless of gravel type or intragravel water temperature. Figure 4 provides a comparison of the results of the equations below with the results of the calibration tests.

Apparent Velocity = 0.0132 * Meter Reading (Span 1) + 0.06; used for flowmeter readings between zero and 650

Apparent Velocity = 0.0261 * Meter Reading (Span 1) - 8.50; used for flowmeter readings greater than 650

Field measurements of apparent velocity were made by first removing the cap on the well and attaching a 44-inch long extension of PVC pipe with a water-tight coupler on top of the well so that the top of the extension was above the water's surface. The flowmeter control unit was placed in a two-person raft which was anchored by attaching it to a 4-foot length of reinforcing bar driven into the streambed approximately 2.5 feet to the side and downstream from the well. The control unit was not waterproof and considerable effort was made to keep it dry. The flowmeter's probe was held in the surface flow for about 30 seconds so that the thermistors could rapidly reach thermal equilibrium with the water. The probe of the Extech thermometer and the flowmeter's probe were then inserted into the PVC extension and both were slowly pushed into the well until contact was made with the reinforcing bar.   The two probes were raised about 2 inches so that they were approximately 12 inches below the substrate surface where chinook salmon egg pockets typically occur (Vronskiy 1972). The North scribe mark on the flowmeter's probe and attaching aluminum push rod were positioned so that they always faced in a downstream direction. A clamp was attached to the aluminum push rod to hold the probe stationary while taking the measurement. The digital readings for each pair of thermistors were monitored until thermal equilibrium with the water in the well was achieved as indicated by a change in the meter's readout of less than 2 units per minute; this usually required about five minutes. Then the initial readings for each thermistor pair and water temperature in the well were recorded. The heat pulse and a stopwatch were simultaneously started and readings for all four pairs of thermistors were monitored. When the maximum reading was observed, the final readings for all four thermistor pairs and the test duration were quickly recorded. Due to the high intragravel flow rates measured, the heat pulse usually "washed out" prior to the recommended test duration of 2 minutes and 23 seconds. During most measurements, the flowmeter reading reached a maximum after about one minute and 30 seconds, after which the reading began to rapidly decline. In some instances, particularly where flow rates were high, the maximum reading occurred after 45 seconds and conversely where flow rates were low, the maximum reading occurred after 2 minutes and 15 seconds. When extremely low readings were observed, the test was repeated with the digital output "span" set at 4X, which multiplied the reading by a factor of four, or 8X, which multiplied the reading by a factor of eight. Tests were also repeated when negative readings were observed. The value used to compute apparent velocity was the maximum final reading minus the initial reading of the thermistor pair with the highest net reading. All readings measured at output spans of 4X and 8X were adjusted to a span of 1X before computing apparent velocity.

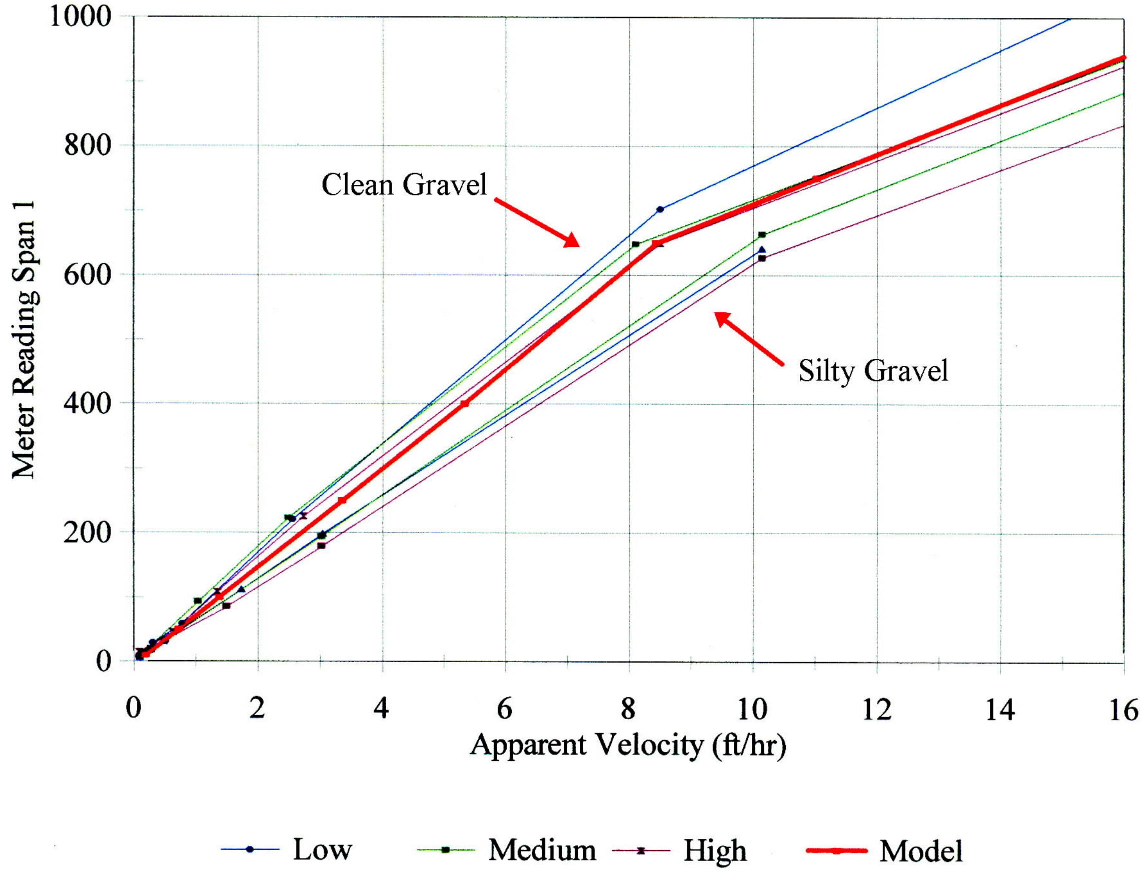

Figure 4. Calibration results for the KVA Model 40L Geoflo Groundwater Flowmeter for two gravel mixtures and three water temperatures. The upper three lines present the results for the clean gravel mixture (porosity of 0.262) for the low, medium, and high water temperature tests. The lower three lines present the results for the silty gravel mixture (porosity of 0.209) for the low, medium and high water temperature tests. The line labeled "Model" represents the relationship used to estimate apparent velocity from all field measurements.

Four sets of apparent velocity measurements were made. The first set was made at 5 riffles near Lovers Leap (riffles R12A, R12B, R13, R19, R19A) on 15 and 16 October 2000, which was immediately prior to the 1,100-cfs pulse flow. The second set was made at all 82 well sites between 4 and 13 November 2000, which began shortly after the pulse flow. The third set was made at all well sites between 25 and 28 December 2000 after spawning had finished. The fourth set was made at all well sites between 5 and 14 February 2001 after two modest rain storms.

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

One intragravel D.O. sample was collected from each of the 82 piezometers during seven surveys between 30 October 1999 and 15 February 2001 and during one survey on 15 and 16 October at five riffles near Lovers Leap. Samples were collected using a 50-ml polypropylene, disposable syringe (Henke-Sass Wolf GmbH, Germany) fitted with a six-inch long, 1/8-inch inside diameter polypropylene tube and a tapered connector that provided an airtight seal between the piezometer's tubing and the syringe's tubing. Water samples were collected by first slowly withdrawing 50-ml of water, the approximate volume of water in the piezometer's tubing, and then using it to rinse the sample bottle. Then a 60-ml sample was slowly withdrawn and injected into a LaMotte sample bottle. A LaMotte test kit, model EDO/AG-30 was used for the analysis. The LaMotte test uses the azide modification of the Winkler Method and a LaMotte Direct Reading Titrator for the final titration. The kit measures D.O. concentration in 0.1 parts per million (ppm) increments. Kit reagents were replaced for each survey. Immediately after the samples were collected at a site, they were fixed and placed in an ice chest. They were analyzed at room temperature within 10 hours after collection.

A surface D.O. sample was collected at each site at the same time the intragravel samples were collected. The percent saturation of dissolved oxygen for the intragravel samples was computed by dividing the D.O. concentration of the intragravel sample by the D.O. concentration of the surface sample.

INTRAGRAVEL WATER TEMPERATURE

Intragravel and surface water temperatures were measured to provide an index of downwelling of surface flow. High D.O. levels and presumably high downwelling rates corresponded to piezometer sites where the magnitude and fluctuation of intragravel water temperatures matched those in surface water temperatures in the Stanislaus River in fall 1996 (CMC 1997) and fall 1999 (CMC 2001a). Conversely, low D.O. levels and presumably low downwelling rates corresponded to sites where intragravel water temperatures were relatively high and stable (CMC 1997, 2001a).

An *Onset StowAway TidbiT* thermograph was buried with each piezometer inside perforated PVC pipe to record intragravel water temperatures at 30-minute intervals. Thermographs were also installed in perforated PVC pipes chained near the stream margin to record surface water temperatures at riffles R5, R10, R14, R28A, R59, and R76. Comparisons between surface and intragravel measurements at riffles where no surface thermograph was installed utilized the surface data collected at the closest riffle. Measurements began on 25 September 2000 at 8:00 a.m. prior to the installation of the piezometers and ceased when the piezometers were removed between 5 and 15 February 2001.

VERTICAL HYDRAULIC GRADIENT

The ratio of the differential head to the depth of the piezometer below the sediment-water interface (Lee and Cherry 1978; Dahm and Valett 1996) is known as the vertical hydraulic gradient (VHG). Negative VHG measurements indicate the downwelling of surface flow and positive values indicate the upwelling of intragravel flow. VHG was measured at the piezometers during each survey. The differential head was measured with a manometer consisting of a 9-ft long, 1/4-inch inside-diameter, clear PVC tube. One end of the tube of the manometer was connected to the piezometer's tubing with an air tight connector and the other end of the tube was attached to a wooden stake that was held near the substrate’s surface (Lee and Cherry 1978; Dahm and Valett 1996). A silicone pipet bulb with emptying and filling valves was attached to the middle of the tubing with a t-connector to facilitate filling the manometer with water. Measurements were made by partially filling the manometer's tubing with water and then holding the middle of the tube at eye level to form a loop with two vertical tubes and a single air bubble at the top of the loop. Before the measurement was made, the manometer was inspected to ensure that there were no air bubbles trapped in the water columns or fine sediment/debris blocking flow through the tubes. The differential head was read as the difference in height in centimeters between the water levels in the two tubes. Measurements were recorded as negative when the water level in the side of the tube connected to the piezometer was lower than the level in the side of the tube held at the substrate’s surface. VHG is computed as the differential head divided by 30 cm, which is the approximate difference in elevation between the holes in the copper tubing of the piezometer and the substrate’s surface.

REDD EXCAVATIONS

Entombed alevins and dead eggs were counted when superimposed and non-superimposed chinook salmon redds were excavated. Superimposed chinook salmon redds were partially excavated when the piezometers and thermographs were retrieved from 19 artificial redds in early February 2001 (Table 11 in Appendix 2). Only the areas immediately surrounding the piezometers were excavated to a depth of 12 inches with a shovel and so only the margins of the superimposed redds were examined. As the gravel was shoveled downstream, the dead alevins and broken membranes of dead eggs, both of which were white and buoyant, were counted as they floated downstream. The membranes of dead eggs were relatively difficult to observe in the turbid water and some were probably missed.

Non-superimposed redds were more fully excavated on 14 March 2001. Five redds were excavated at Riffle R19A, a restoration riffle, and seven redds were excavated near piezometers P3 and P4 in Riffle R20, which was a control riffle used by numerous spawning salmon. All redds were isolated and not superimposed and they were the typical size and shape of a redd made by three-year-old fish. Excavations were made with a shovel in a three-foot diameter area at the upstream edge of the redd’s tailspill to a depth of 12 inches, the typical location of egg pockets made by chinook salmon (Vronskiy 1972). Each shovel full of gravel removed from the redd was raised in the water column and slowly spilled back onto the streambed. As the gravel was spilled, the dead eggs and alevins were counted as they floated downstream.

STATISTICAL ANALYSES

All statistical analyses, including *t*-tests, *F*-tests, correlations, and regressions, were made using the Statistix Version 7.0 software program (Analytical Software 2000). Scatter plots with means and error bars were generated with SigmaPlot for Windows Version 7.0.

RESULTS

The Department of Fish and Game's preliminary estimate of chinook salmon escapement (grilse and adults) to the Stanislaus River below Goodwin Canyon in fall 2000 is approximately 12,000 fish (Robert Kano, personal communication, see "Notes"). During fall 1998 and fall 1999, the preliminary escapement estimates for the Stanislaus River are 3,147 and 4,500 fish, respectively.

DISTRIBUTION AND TIMING OF SPAWNING

A total of 1,081 redds was observed where gravel had been placed at the 18 project riffles and 773 redds were observed at the seven control sites and in natural gravel adjacent to the gravel placement areas between 30 October and 27 December 2000 (Table 3 in Appendix 2). Comparing the same locations surveyed in fall 2000 with those surveyed in fall 1999, the number of redds observed in natural gravel was about 1.1 times greater in 2000 than in 1999, whereas the number observed in the restoration gravel was about 1.5 times greater in 2000 than in 1999. If the fall 2000 preliminary escapement is accurate, the nearly three-fold increase in escapement between fall 1999 and fall 2000 suggests that the total number of redds observed at the KFGRP study sites in fall 2000 may have underestimated the true number.

Spawning began in early October as numerous redds were observed on 12 October 2000 when some of the piezometers were installed. During the first redd survey between 30 October and 3 November, 709 redds were counted, which was 38% of the total observed during the entire season. This was higher than in 1999 when 29.7% of the total number of redds had been counted by 1 November and in fall 1998 when 25% of the redds had been counted by 1 November. In fall 2000, most of the spawning had been completed by mid December. During the fifth survey between 15 and 17 December, 95 new redds and 24 live adult fish were counted; whereas, only 13 new redds and no fish were observed during the last survey between 25 and 29 December.

Chinook salmon spawned at all of the project and control sites, although only a total of 6 redds was observed at riffles R59, R76, and R78, which are the downstream most sites (Table 3 in Appendix 2). As occurred in fall 1998 (CMC 2001a) and fall 1999 (CMC 2001b), redd densities were highest at the upstream sites and they gradually declined in a downstream direction (Figure 5). There were strong negative correlations between redd densities and the distance downstream from Goodwin Dam for all three restoration gravel mixtures and the control sites. The following table presents the coefficient and constant for the variable for the distance downstream from Goodwin Dam, the total degrees of freedom (*df*), the probability level (*P*) for the regression, and the adjusted-R^2 for linear regressions between the density of redds and the distance downstream from Goodwin Dam for each gravel mixture.

Gravel Mixture	Coefficient	Constant	*df*	*p*	adj-R^2
Stanislaus rock 1/4-inch screen	-0.03270	0.5484	5	0.0302	0.663
Stanislaus rock 3/8-inch screen	-0.02588	0.5120	5	0.0194	0.727
Tuolumne rock 3/8-inch screen	-0.01972	0.3728	5	0.0060	0.845
Control Sites	-0.01734	0.2910	6	0.0003	0.929

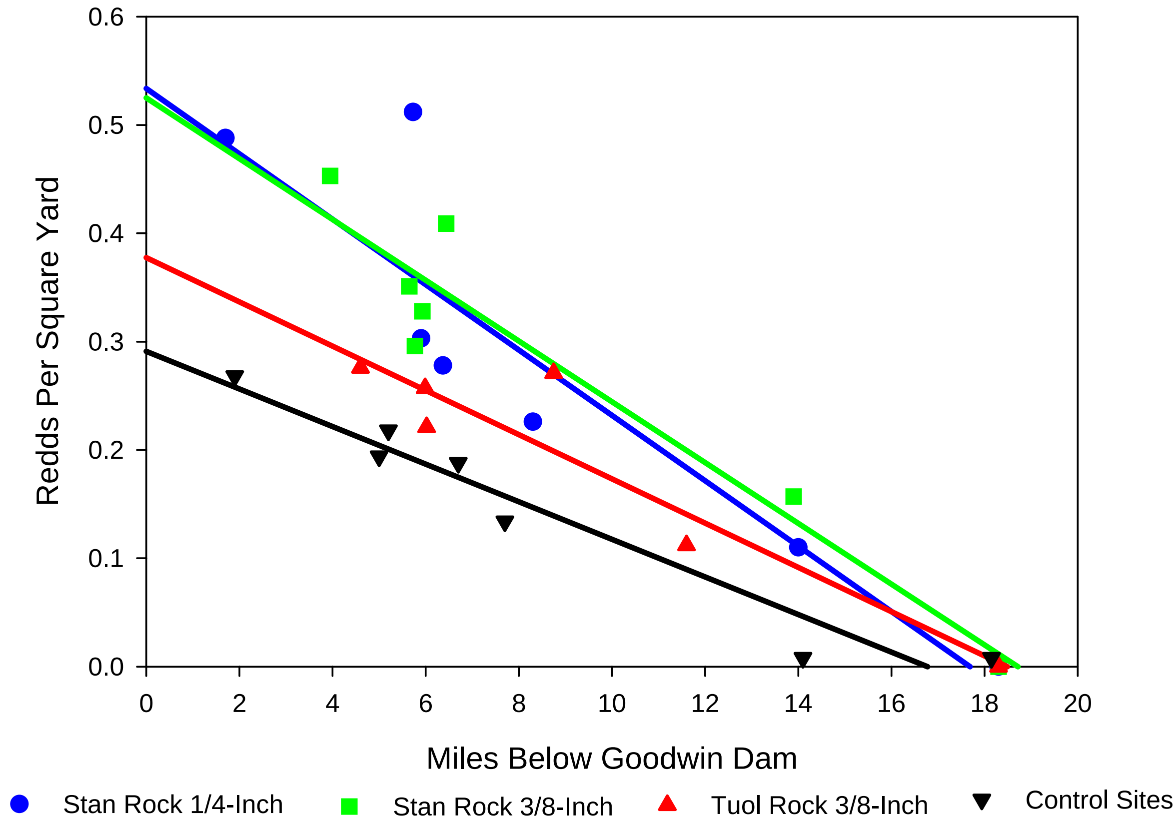

Figure 5. Chinook salmon redd densities at project sites that received three different mixtures of gravel: (1) Stanislaus River rock cleaned with a 1/4-inch screen, (2) Stanislaus River rock cleaned with a 3/8-inch screen, and (3) Tuolumne River rock cleaned with a 3/8-inch screen and the control sites relative to the distance below Goodwin Dam in the Stanislaus River in fall 2000. Regression models are shown as lines. The models for both sizes of Stanislaus River rock assume that at sites 18 miles below Goodwin Dam, redd densities would have been near zero and similar to the densities observed for the Tuolumne River rock and control sites.

A total of 102 redds was observed in fall 2000 at the DFG restoration site in upper Goodwin Canyon, referred to as DFG2 in this report. The gravel was placed at a site that was approximately 80 feet wide by 60 feet long in 1997. By fall 1998, some of the gravel in the center of the riffle had been flushed away by high flows and there were about 144 square yards of spawning habitat in fall 2000. The density of redds at DFG2 was 0.71 per square-yard, which was higher than the densities observed at any of the KFGRP sites. Presumably, high redd densities occurred at DFG2 because it was the upstream most site surveyed and there were few nearby riffles suitable for spawning.

Redd densities were surveyed on 17 December 2000 at four new control sites, R2, R11, R26, and R44, so that spawning activity could be gauged relative to intragravel water conditions at these sites. Redd densities at the new sites were similar to those at the original KFGRP control sites in fall 2000, except that redd densities were slightly high at Riffle R2 and quite low at Riffle R44 (Figure 6). These estimates may not be very accurate because they are based on a single survey made late in the spawning season. During this survey, it was difficult to exclude intact tailspills from redds that may have been constructed in fall 1999 and to count all superimposed redds constructed in fall 2000.

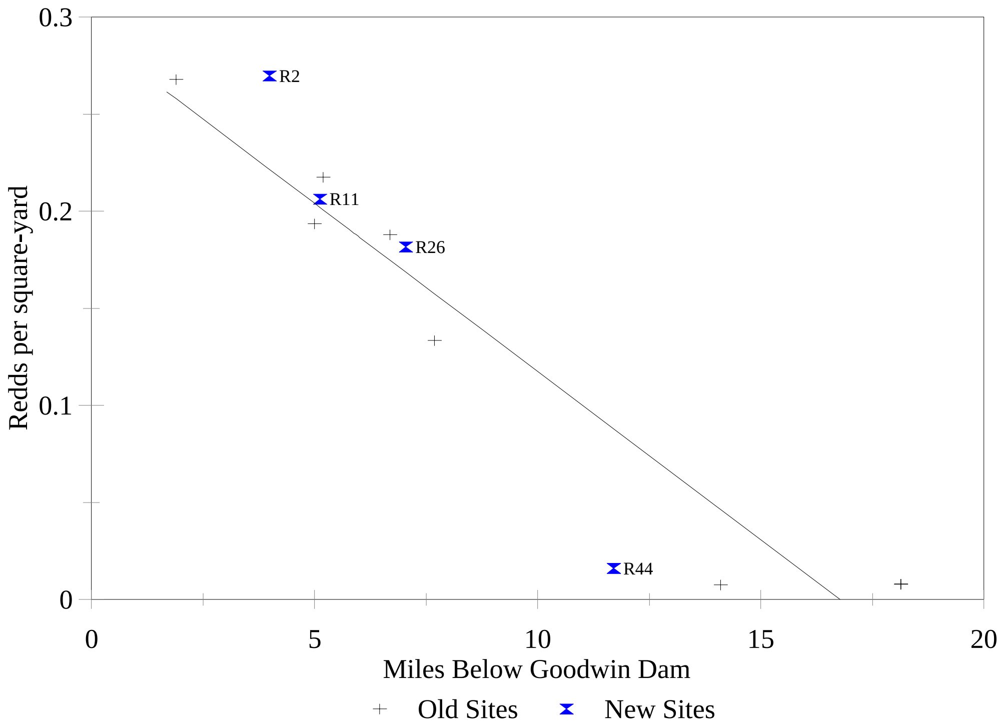

Figure 6. Chinook salmon redd densities at the original control sites measured since 1998 (Old Sites) and the new control sites, R2, R11, R26, and R44, relative to the distance below Goodwin Dam in the Stanislaus River in fall 2000. The regression model for the original control sites is shown as a line. Redd densities were estimated at the original sites based on six surveys between 30 October and 29 December 2000, whereas the estimates at the new sites are based on a single survey on 17 December 2000.

EFFECTS OF GRAVEL SOURCE AND SIZE ON REDD DENSITY

The evaluation of hypotheses III-A, III-B, and III-C regarding spawner utilization of different sources and size distributions of restoration gravel (see the Introduction for details on the hypotheses) had to consider the negative correlation between redd density and the distance downstream from Goodwin Dam. One means of avoiding this location effect was to compare the redd distribution at areas where restoration gravel was placed with adjacent areas in the same riffle where natural undisturbed gravel occurred (Appendix 3). Unlike the fall 1999 observations which indicated that many salmon avoided areas with deep layers of Tuolumne River rock (CMC 2001b), the distribution of redds in fall 2000 indicated that all three types of restoration rock were well utilized by spawning chinook salmon, particularly at the sites upstream from Willms Pond (Riffle R20). Statistical tests of pre- and post-project redd densities would not be meaningful because salmon escapement was considerably different between the surveys.

The hypotheses were also tested with two-tailed F-tests that compared the residual variances, slope, and elevations of the regressions of redd density versus distance downstream between the different gravel mixtures shown in Figure 5 (Snedecor and Cochran 1989, pages 390-393). Before the tests were conducted, the regressions for both sizes of Stanislaus River rock were recomputed based on the assumption that redd densities would have been near zero approximately 18 miles below Goodwin Dam as occurred with the Tuolumne River rock and control sites. Otherwise, the unadjusted regressions for the Stanislaus River rock sites would suggest that salmon spawn further downstream in the control sites and Tuolumne River rock sites than in the relatively well used Stanislaus River rock sites. Furthermore, comparisons of the unadjusted regressions might have falsely suggested that the regression slopes for the Stanislaus River rock sites were significantly higher than those for the Tuolumne River rock and control sites.

To compare the regressions, the *F*-test requires that the variance of the regressions are not significantly different before testing the slope and elevation of the regressions. There were no significant differences between the variances of the regressions for most of the comparisons and so it was possible to compare most of the slopes and/or elevations of the regressions. However, the variances for the regressions for Stanislaus River rock washed with a 1/4-inch screen and the control sites were significantly different and so their slopes and elevations could not be compared. The results of the *F*-tests for the fall 2000 comparisons are summarized below and presented in detail in Table 4 (Appendix 2).

- The elevation of the regression for the sites with Stanislaus River rock cleaned with a 3/8-inch screen was significantly greater ($P = 0.018$) than the elevation for the regression with the Tuolumne River rock sites. Therefore, redd densities at the sites with Stanislaus River rock cleaned with the 3/8-inch screen were greater than the densities at the sites with Tuolumne River rock.
- The slope of the regression for the sites with Stanislaus River rock cleaned with a 3/8-inch screen was significantly greater ($P = 0.027$) than the slope for the regression with the control sites. Therefore, redd densities at the Stanislaus River rock sites were greater than the densities at the control sites, particularly in the upstream areas.
- The elevation of the regression for the Tuolumne River rock sites was significantly greater ($P = 0.009$) than for the regression with the control sites. Therefore, redd densities at the Tuolumne River rock sites were greater than the densities at the control sites. The opposite was observed in fall 1999, when redd densities may have been greater ($P = 0.096$) at the control sites than at the Tuolumne River rock sites.
- It was not possible to compare the regressions for the sites with Stanislaus River rock washed with a 1/4-inch screen and the control sites because the variances were significantly different ($P = 0.016$).
- None of the other comparisons of slopes or elevations for the regressions were statistically significant ($P \geq 0.115$). Although the slope of the regression for the sites with Stanislaus River rock cleaned with a 1/4-inch screen was 52% higher than the slope for the regression for the Tuolumne River rock sites, the difference was not significant ($P = 0.115$)

STREAMBED ELEVATION

Sediment transport modeling suggests that the mobilization of the restoration gravel would have been limited during spring 2000 when flow releases from Goodwin Dam ranged between 3,000 and 3,500 cfs from 28 February and 9 March and between 1,300 and 1,500 cfs between 13 April and 12 June. These are relatively average flows for the post-New Melones Dam period (1979-present), during which flows of at least 3,070 cfs would have a 50% probability of occurring in a given year (Kondolf et al. 2001). The results of a bed mobility analysis for KFGRP riffles R1, R5, R28A, and R78 suggest that flows of around 5,000 to 8,000 cfs are necessary to mobilize the median diameter (D_{50}) of the channel bed material (Kondolf et al. 2001). Flows of 5,000 cfs and 7,350 cfs would be expected to occur approximately every 3.4 years and 22 years, respectively (Kondolf et al. 2001).

The estimated volume of gravel mobilized from the 18 project sites confirms the prediction based on the Kondolf et al. (2001) sediment transport analysis that only a limited amount of gravel would be mobilized during the spring 2000 peak flows of 3,500 cfs. Gravel movement primarily occurred at only four of the 18 project sites where instream structures confined the flow and caused localized scour within these four project riffles during spring 2000. At riffles R5, R13, R43, and R78, between 48 and 79 cubic yards of gravel (9.2% to 19.5% of the total placed) was mobilized from the sites between December 1999 and September 2000 (Table 5 in Appendix 2). Shear stress was probably relatively high at Riffle R5, where the channel was relatively narrow (81 feet) and a large willow, approximately 18 inches in diameter, was growing horizontally near the ground on the left bank. Similarly, a series of large boulders on river right of the tail of Riffle R13 (shown in Figure 10 of Appendix 3), a large bridge pillar on river left immediately upstream of Riffle R43, and a large heavily vegetated mid-channel gravel bar on river left approximately 50 yards upstream of Riffle R78 would also have increased gravel movement rates. In addition to the areas where the flow was concentrated by the instream structures, gravel was mobilized from the riffle tails and small gravels were winnowed away from the entire riffle's surface. The bed elevation profiles show the gravel movement at riffles R5, R43, and R78, whereas most of the gravel movement occurred downstream of the transect at Riffle R13 (Appendix 4). Chinook salmon spawned where the gravel had eroded away at riffles R5, R13, and R43 and so spawning habitat quality declined only slightly if at all (Appendix 3). Very few fish spawned at Riffle R78 because it is too far downstream for most spawners, however, the loss of gravel there resulted in high water velocities that may have reduced the suitability of the site for spawning.

A substantial amount of gravel moved within Riffle R14 in response to high flows from Wildcat Creek, which enters the Stanislaus River immediately upstream of this riffle on river left. The contour map of this riffle (Figure 11 of Appendix 3) shows where approximately 42 cubic yards of gravel were eroded from the upstream margin of the site and deposited a short distance downstream within the site. The bed elevation profile for Riffle R14 shows the area near river left where deposition occurred (Appendix 4). There was a net increase of 20 cubic yards of natural gravel in the project area and presumably gravel was eroded from the bed below the mouth of Wildcat Creek and deposited within the site (Table 5 in Appendix 2). Chinook salmon spawned where both erosion and deposition occurred (Figure 11 of Appendix 3) and so spawning habitat quality was probably unaffected by these changes.

Between 2 and 34 cubic yards of gravel (0.2% to 19.7% of the total placed) were mobilized from the other 13 project sites (Table 5 in Appendix 2). At these riffles, almost all of the gravel mobilization resulted from the winnowing of small gravels from the riffle's surface, which did not affect the distribution of chinook salmon redds or the contour of the riffles' surfaces (Appendix 3).

Neither the size of the gravel, the pre-project gradient of the bed upstream of the natural riffle's crest where the gravel was placed, nor the channel width had a significant effect on the volume of gravel mobilized from the 18 project sites. Because much of the erosion resulted from the winnowing of small gravel from the riffle's surfaces, it would be logical to assume that erosion rates would have been higher at the sites that received gravel with a D_{50} of about 27 mm that was washed with a 1/4-inch screen compared to the sites that received gravel with a D_{50} of about 37 mm that was washed with a 3/8-inch screen. However, the opposite occurred indicating that other factors were more important. A mean of 0.076 cubic yards of gravel was mobilized from each square yard of surface area from the sites that received gravel washed with the 1/4-inch screen whereas a mean of 0.163 cubic yards of gravel was mobilized from each square yard of surface area from the sites that received gravel washed with a 3/8-inch screen. The difference is not significant ($P = 0.125$).

Hypothesis IV-A, which presumed that sediment transport rates would be lower if gravel is placed within tails of natural pools, was also rejected for flows up to 3,500 cfs. The volume of gravel mobilized from the high-, moderate-, and low-crested riffles is 0.114, 0.164, and 0.122 cubic yards of mobilized gravel per square yard of riffle area, respectively. These differences are not significant; P is 0.50 for the comparison between high- and moderate-crested riffles and P is 0.55 for the comparison between moderate- and low-crested riffles.

Hypothesis IV-B, which presumed that sediment transport rates would be lower if the gravel was placed at riffles adjacent to functional floodplains, was rejected as well for flows up to 3,500 cfs. The mean volume of gravel mobilized from riffles R5, R28A, R29, and R43, which were adjacent to small but functional floodplains, is 0.254 cubic yards of mobilized gravel per square yard of riffle area. This is not significantly different ($P = 0.134$) from the volume of gravel mobilized from the riffles without adjacent floodplain, which is 0.099 cubic yards of mobilized gravel per square yard of riffle area. One reason that gravel movement was greater at the sites with functional floodplains is that the bed shear stress at flows up to 3,500 cfs was probably lower in the channels widened by gravel mining than at the relatively narrow unmined sites that had functional floodplains. This may not be the case at higher flows. Another reason is that two of the four sites with functional floodplains, also contained unusual hydraulic controls (the horizontally growing willow at Riffle R5 and the bridge pillar at Riffle R43) that created localized scour of relatively large volumes of gravel.

A linear regression analysis indicates that the presence of unusual hydraulic controls at Riffles R5, R13, R43, and R78 explained 52% of the variability ($P = 0.001$) in the volume of mobilized gravel among restoration sites, whereas gravel size (D_{50}), bed gradient, and channel width were not significantly correlated ($P \geq 0.36$). Although the presence of functional floodplain was significantly correlated ($P = 0.046$), the relationship was positive indicating that sediment transport rates were higher for riffles adjacent to floodplain habitat compared to mined channels without floodplain. Again, these results are probably only true for moderate flows of 3,500 cfs in the Stanislaus River.

SUBSTRATE PERMEABILITY

Permeability in Undisturbed Gravel

The mean permeability of undisturbed gravel measured at a depth of 12 inches at all project sites ($N = 74$) was 31,375 cm/hr between 10 and 17 November 2000. This is significantly greater ($P = 0.015$) than the mean permeability of 5,363 cm/hr that was measured in undisturbed gravel in the control sites (*N* = 31) during the same survey (Table 5 in Appendix 2). This was also significantly lower (*P* = 0.000) than the mean permeability of 88,013 cm/hr that was measured in undisturbed gravel at the project sites (*N* = 71) between 14 and 19 December 1999, which was about three months after construction and prior to high flows or turbid storm runoff (CMC 2001b).

There are no significant differences ($P \geq 0.692$) in permeability in fall 2000 among the different gravel types where measurements were taken in restoration gravel at least 18 inches deep. The mean permeability at sites with Stanislaus River rock washed with a 1/4-inch screen were nearly identical to the mean for the sites with Tuolumne River rock washed with a 3/8-inch screen for the fall 2000 survey. This was a surprising result considering that the initial mean permeability for the Tuolumne River rock was about 35% higher than the initial mean permeability for the Stanislaus River rock washed with a 1/4-inch screen in fall 1999. The following table presents the mean permeability and sample size (*N*) for each gravel type measured in fall 1999 and fall 2000 where the restoration gravel was at least 18 inches deep.

Gravel Type	Fall 2000 Mean Permeability	*N*	Fall 1999 Mean Permeability	*N*
Stanislaus River Rock 1/4-in Screen	44,971 cm/hr	13	150,990 cm/hr	8
Stanislaus River Rock 3/8-in Screen	37,493 cm/hr	20	171,436 cm/hr	20
Tuolumne River Rock 3/8-in Screen	45,454 cm/hr	15	204,827 cm/hr	6

The mean permeability in undisturbed gravel declined significantly (*P* = 0.003, *N* = 25) from 41,302 cm/hr in June and July 2000 to 10,051 cm/hr in November 2000 at the project sites between R15 and R57 based on a paired t-test (Figure 7). This decline was probably in response to high rates of fine sediment intrusion that occurred during a 5-day 1,100-cfs managed pulse flow in late October. High rates of fine sediment intrusion also occurred at the same sites during the managed pulse flow release in spring 2000 (CMC 2001b). In contrast, the mean permeability may have increased significantly (*P* = 0.072, *N* = 23) from 48,159 cm/hr in June and July 2000 to 92,292 cm/hr in November 2000 at some of the upstream sites, R5, R12A, R12B, and R14A (Figure 7). This increase suggests that fines were flushed from these riffles during the pulse flow although there was no gravel movement. The increases in permeability at sites R12A, R12B, and R14A were unexpected because permeabilities declined at these sites in response to pulse flow releases made in spring 2000 (CMC 2001b). There was no significant change (*P* = 0.470, *N* = 16) in the mean permeability at sites R1, R13, R14, and R78 between the summer 2000 survey (12,968 cm/hr) and the fall 200 survey (8,063 cm/hr; Figure 7).

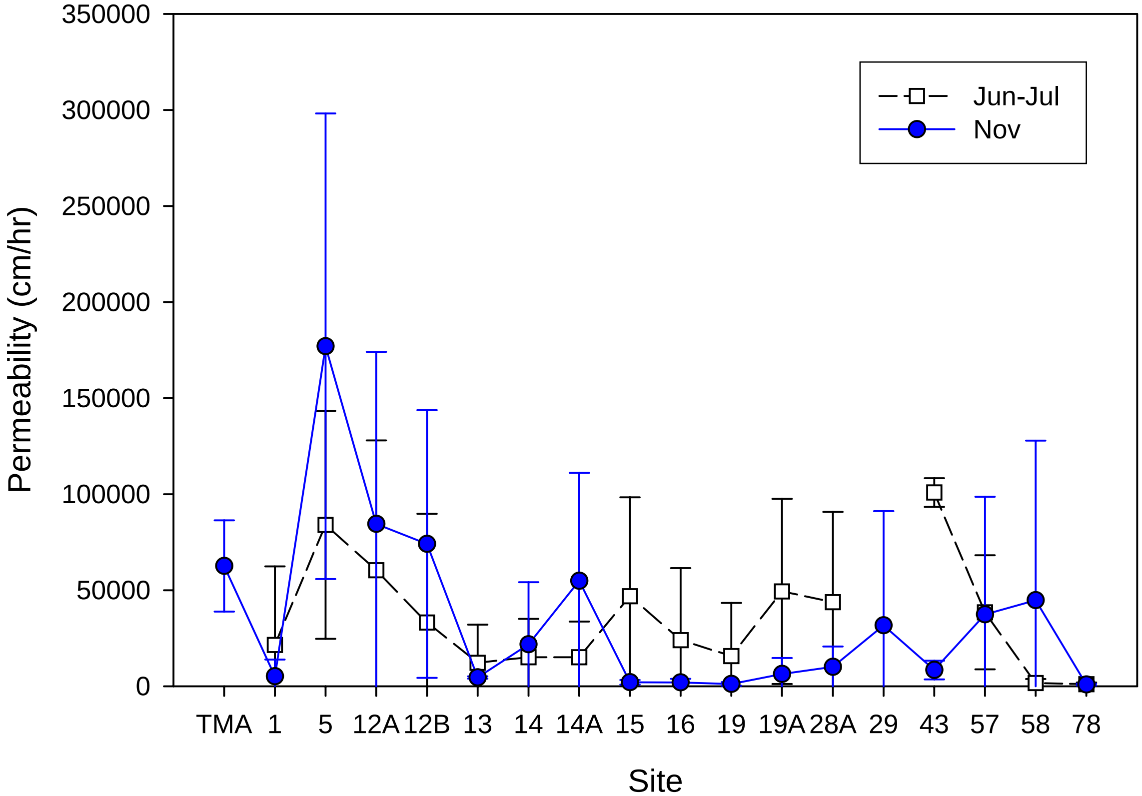

Figure 7. Scatter plot showing the mean permeability and standard deviation (error bars) at a depth of 12 inches in undisturbed gravel within project riffles in the Stanislaus River between 27 June and 5 July 2000 (Jun-Jul) and between 11 and 17 November 2000 (Nov). Sites are arranged along the x-axis from the upstream most site (TMA) to the downstream most site (R78).

The mean permeability was generally highest at the upstream sites, particularly TMA, R5, R12A, and R12B (Figure 7), which suggests that high fine sediment intrusion rates at the downstream sites were mostly associated with the past and/or current gravel mining operations near Lovers Leap and residential development between the Orange Blossom Bridge and Oakdale. High rates of fine sediment intrusion appear to be a highly localized problem because there were large differences in permeability between nearby project sites. For example, sites R12A, R12B, and R13 were all within 50 meters of each other and yet the mean permeability for sites R12A and 12B was about 80,000 cm/hr (range 2,558 to 199,923 cm/hr) and the mean permeability for site R13 was about 4,500 cm/hr (range 3,986 to 5,132 cm/hr). Similarly, the mean permeability at site R14A was relatively high (mean of about 55,000 cm/hr) compared to nearby sites R14, R15 and R16 (mean of about 8,500 cm/hr). The primary source of the fine sediments was most likely the accumulated fines on the streambed of the mined channels near Lovers Leap, because other sources such as streambank erosion, which was highest at sites R12A and R12B, and tributary input, which was highest at R14, cannot account for the observed patterns in permeability among sites.

Permeability in Chinook Salmon Redds

The permeability was measured in the vicinity of the egg pockets of non-superimposed chinook salmon redds and in the artificial redds to provide comparisons between project and control sites. However, the measurements suffered from two sources of uncertainty. One source of uncertainty is the effect that fine sediment intrusion would have on redd permeability over time. Permeability measurements that were repeated at the same six redds during two surveys, one in mid November and the other in December and January, suggest that permeability in the egg pocket declined from a mean of 77,035 cm/hr to 36,720 cm/hr between the two surveys (Table 6 in Appendix 2). However, the difference was not significant (P = 0.429) based on a paired *t*-test.

To conduct another test of the effect of a redd's age on permeability with a much larger sample size, comparisons were made between relatively new redds and old redds, each of which were measured only once. The results were similar to those above in that mean permeability for new redds is higher than the mean for the older redds, although the difference is also not significant. In the project sites, there is no significant difference ($P = 0.289$) between the mean permeability of 89,589 cm/hr for redds ($N = 49$) measured in mid November 2000 that were less than 10 days old and the mean of 64,328 cm/hr for redds ($N = 15$) measured in December 2000 and January 2001 that were between 30 and 60 days old. Similarly, there is no significant difference in the mean permeability (P = 0.953) between redds measured in the control sites that were less than 10 days old (14,577 cm/hr, $N = 9$) and redds that were between 30 and 60 days old (14,145 cm/hr, $N = 15$).

If fine sediment intrusion caused redd permeability to decline over time, then comparisons of permeability should be made only between similarly aged redds. On the other hand, if fine sediment intrusion had minimal effects on redd permeability, the sample sizes could be greatly increased by using all of the data collected. The two-sample *t*-tests for comparisons between similarly aged redds and for comparisons that used all data combined regardless of redd age presented below, all indicate that redd permeability is significantly higher in project sites than in control sites.

a) Comparisons between redds that were five to seven days old in November 2000 using *t*-tests indicate that the mean permeability of 89,589 cm/hr for 15 redds in project sites is significantly greater ($P = 0.006$) than the mean of 14,577 cm/hr for 9 redds in the seven original control sites.
b) Comparisons between redds that were 30 to 60 days old in December 2000 and January 2001 using *t*-tests indicate that the mean permeability of 64,328 cm/hr for 49 redds in project sites is significantly greater ($P = 0.000$) than the mean of 14,145 cm/hr for 15 redds in the seven original control sites.
c) Comparisons between redds of all ages indicate that the mean permeability of 76,007 cm/hr at 91 redds in the project sites is significantly greater ($P = 0.000$) than the mean of 26,045 cm/hr for 55 redds measured in the 11 control sites.

Another source of uncertainty is that it was impossible to determine whether the 12-inch deep permeability measurement was made in the relatively porous egg pocket, which typically was about 12 inches in diameter, or in the undisturbed gravel within the redd, which typically ranged between 6 and 8 feet in diameter in the Stanislaus River. Although the measurements were taken in the most likely location for an egg pocket, the egg pockets can be located almost anywhere within the redds (Vronskiy 1972, Chapman 1988). There was evidence of this problem from repeated measurements made in the same six redds during a November survey and a December-January survey. Although the permeability declined at four redds between the two surveys as would be expected as fine sediment intrusion occurred, the permeability increased substantially at two of the redds (Table 6 in Appendix 2). This unexpected increase would only occur if the standpipe missed the egg pocket on the first survey but sampled the egg pocket during the second survey. Also troubling is that 61% (20 of 33) of the redd measurements in control sites were indistinguishable from the measurements in undisturbed gravel. Although it is also possible that up to 61% of the measurements did not sample the egg pockets but instead sampled the undisturbed gravel within the redd, extremely high rates of fine sediment intrusion rates would also explain these results.

To minimize the confounding effect of not consistently sampling the egg pockets in salmon redds, comparisons were made with the measurements taken in the "egg pockets" of the artificial redds (Table 7). The mean permeability 53,753 cm/hr for the artificial redds in the project sites is significantly greater ($P = 0.001$) than the mean permeability of 6,365 cm/hr for the artificial redds in the control sites. Although the precise location of the "egg pockets" in the artificial redds was evident from the presence of the well pipe used to measured apparent velocity, these redds were constructed in September and October 2000 and permeability measurements were not taken until early February 2001. Since the artificial redds were old compared to the chinook salmon redds, it is likely that the pulse flow in late October 2000 and the turbid storm runoff in January 2001would have resulted in unusually high fine sediment intrusion rates and low permeabilities in the artificial redds compared to a majority of the salmon redds.

In spite of the uncertainty, the gradual decline in redd permeability with increasing age of the redds regardless of whether measurements were taken in natural or artificial redds suggest that the results are reasonable. Furthermore, the results of the four statistical tests all strongly indicate that redd permeabilities were significantly greater in the project sites than in the control sites. It is also likely that the low permeabilities measured in natural redds probably reflect both high rates of fine sediment intrusion as well as occasionally missing the egg pocket during sampling. Highly localized intrusion of fine sediments provides the best explanation for the highly variable permeabilities observed among the artificial redds in the project sites (range 85 to 343,850 cm/hr).

Predicted egg survivals for both the natural and artificial redds are significantly greater in the project sites than in control sites. For the natural redds, few of which were affected by fine sediment intrusion from high flows, turbid storm runoff, or redd superimposition, the mean predicted survival rate of 61.8% for the project sites was significantly greater ($P = 0.001$) than the mean of 48.1% for the control sites. For the artificial redds, which were affected by high flows, turbid storm runoff, and occasionally redd superimposition, the mean predicted survival rate of 51.0% for the project sites was significantly greater ($P = 0.018$) than the mean of 34.0% for the control sites. These survival estimates, which are based on McCuddin's (1977) laboratory study, probably overestimate the true survival in a natural river such as the Stanislaus River because the chinook salmon eggs were incubated in washed gravel, with high dissolved oxygen concentrations and high intragravel velocity during McCuddin's study. Furthermore, McCuddin simultaneously varied the sand concentration, permeability, and intragravel velocity for each test and so it is not possible to determine whether permeability or the other two factors affected egg survival.

APPARENT VELOCITY AND REDD SUPERIMPOSITION

The apparent velocity in artificial redds declined rapidly after a 5-day 1,100-cfs managed pulse flow in late October 2000, whereas redd superimposition and turbid runoff from two modest rain storms in January 2001 had relatively little effect. The mean apparent velocity was 6.6 feet/hour for measurements taken in mid October at 12 redds in riffles R13, R19, and R19A seven days after the redds were constructed, but before the pulse flow and before all but a few salmon had begun to spawn. Shortly after the pulse flow in early November, the mean apparent velocity was 2.2 feet/hour at seven non-superimposed redds, which was significantly lower based on a paired t-test ($P = 0.024$) than the mean for the mid October measurements. Redd superimposition obscured three of the wells at these redds which prevented apparent velocity measurements for the November survey.

At another seven redds at riffles R12A and R12B that were constructed on 25 September 2000, the apparent velocities also declined after the pulse flow, although the change was not significant. The mean apparent velocity at these redds measured on 15 and 16 October 2000 was 4.1 feet/hour, which was not significantly different based on a two-sample t-test ($P = 0.300$) from the mean for the 12 redds measured at riffles R13, R19, and R19A in mid October, nor was it significantly different based on a paired t-test ($P = 0.289$) from the mean of 1.1 feet/hour for four of the same redds that were not superimposed at riffles R12A and R12B in early November after the pulse flow.

Apparent velocities among all artificial redd sites measured in early November 2000, late December 2000, and early February 2001 were affected by three factors, although only two of the comparisons had statistically significant differences based on two-sample t-tests.

1) Apparent velocities were generally higher in project sites than in control sites, although none of the comparisons had statistically significant differences;
2) Apparent velocities were generally higher in redds scoured by redd superimposition, moderate in redds unaffected by redd superimposition, and lowest in redds buried with gravel from a superimposed redd, although none of the comparisons had statistically significant differences; and
3) Apparent velocities were relatively unchanged between the November and December surveys and the differences were not significant ($P \geq 0.47$). Apparent velocities declined by the February survey after turbid runoff from two modest rain storms. The differences between the December and February surveys were highly significant ($P = 0.005$) for the unaffected redds in the project sites based on two-sample t-tests and for all redds combined ($P = 0.004$) based on paired t-tests, and possibly significant ($P = 0.065$) for the redds buried by redd superimposition in the project sites. None of the other comparisons for redd types between the December and February surveys were significant ($P \geq 0.32$).

The following table presents the mean apparent velocities for artificial redds that were unaffected, scoured, or buried by redd superimposition in project and control sites for the November, December, and February surveys based on the estimates presented in Table 7 in Appendix 2.

	Control Sites			Project Sites		
Survey	Buried	Unaffected	Scoured	Buried	Unaffected	Scoured
November	1.50 ft/hr N = 2	2.03 ft/hr N = 11	2.63 ft/hr N = 6	2.65 ft/hr N = 4	2.65 ft/hr N = 37	3.53 ft/hr N = 11
December	1.50 ft/hr N = 2	2.19 ft/hr N = 9	5.95 ft/hr N = 6	2.60 ft/hr N = 17	2.89 ft/hr N = 16	2.86 ft/hr N = 17
February	0.50 ft/hr N = 2	0.90 ft/hr N = 9	1.67 ft/hr N = 6	1.33 ft/hr N = 17	1.13 ft/hr N = 16	2.24 ft/hr N = 17

Effects of Streamflow on Apparent Velocity

Although the streamflow was different for each of the apparent velocity measurements and streamflow would be expected to affect apparent velocity, the effects of the flow changes on the apparent velocity measurements appear to be inconsequential. The initial apparent velocity measurements in mid October, which were the highest observed, were made at the relatively low flow of 300 cfs. By the early November measurements, apparent velocities declined although the flow releases increased to 375 cfs. This 25% increase in flow would be expected to increase apparent velocities by as much as 25%, assuming that depth and the hydraulic gradient also increased by 25%, if the concentration of fines and all other factors remained the same. However, the apparent velocities declined from 6.6 feet/hour in mid October to 2.2 feet/hour in early November at the recently constructed artificial redds.

A subsequent flow reduction from 375 cfs to 350 cfs (7%) for the late December measurements resulted in no detectable change in the apparent velocities. The mean apparent velocity actually increased from 2.51 feet/hour in early November to 3.02 feet/hour at artificial redd sites measured during both surveys in spite of the reduction in flow. The difference was not significant (P = 0.321) based on a paired *t*-test.

Another flow reduction to 300 cfs for the early February measurements at all sites, except Riffle R78, resulted in a significant decline in the apparent velocities that was a much greater magnitude than would be expected from the reduction in flow alone. The apparent velocity declined from a mean of 2.93 feet/hour for the December survey to a mean of 1.53 feet/hour for the early February survey at artificial redds measured during both surveys, except for those at Riffle R78. This difference was significant ($P = 0.001$) based on a paired *t*-test. Since the apparent velocity declined by 52% while flows declined by 14% between the December and February surveys, it is highly unlikely that the reduction in flow was a significant cause of the decline in apparent velocities between the two surveys.

Flows declined again to 270 cfs on 15 February 2001 when the apparent velocities were measured at Riffle R78. The mean apparent velocity at this riffle declined from 3.2 feet/hour in late December to 0.3 feet/hour in mid February (Table 7 in Appendix 2). Again since the flows declined by only 23%, it is highly unlikely that the reduction in flow was the sole cause of the decline in apparent velocities at Riffle R78.

Direction of Intragravel Flow

The intragravel flow in the artificial redds was not always in a downstream direction. Sensors 4, 5, or 6 of the apparent velocity meter gave the highest readings compared to the other sensor pairs for 17%, 15%, and 19% of the measurements made during the November, December, and February surveys, respectively, which indicates that the direction of intragravel flow was upstream. Sensors 3 and 7 gave the highest readings for 3%, 3%, 9% of the measurements for the November, December, and February surveys, respectively, which indicates that intragravel flow was sideways relative to the direction of the surface flow. Although upstream and sideways flows were usually associated with apparent velocity estimates of less than 1 foot/hour, high sideways and upstream flows were observed at a few artificial redds. For example, sideways flows between 2.4 and 2.8 feet/hour were measured at R12A P4 and upstream flows between 1.6 and 3.4 feet/hour were measured at R29 P3. It is likely that sideways and upstream flows occurred whenever fine sediment intrusion minimized downwelling of surface flow such that groundwater flow provided most of the flow in the egg pocket.

Redd Superimposition Rates

By late December, redd superimposition occurred at 58 of the 82 (71%) artificial redds that were constructed at the study sites prior to 14 October 2000 (Table 7 in Appendix 2). Superimposition rates were particularly high (82%) at the upstream sites between riffle R1 and R29 where redd densities ranged between 0.221 and 0.453 redds per square-yard. Twelve (15%) artificial redds were completely dug up which presumably would have destroyed all of the eggs in an actual salmon redd. Nineteen (23%) were partially buried under the tailspills of superimposing redds, which would be expected to reduce intragravel flow and reduce emergence rates for alevins. Seven (9%) were disturbed when a redd was constructed immediately on top of the artificial redd, which presumably would have destroyed at least some of the eggs in an actual salmon redd. Twenty (24%) were partially scoured away by salmon that used some of the artificial redd's gravel to construct a redd slightly downstream of the artificial redd. The scouring away of gravel frequently increased intragravel flow in the egg pocket of the artificial redds. Furthermore, scouring probably harmed few eggs nor would it affect emergence rates since only the surface gravel of the redds was disturbed.

Relation between Apparent Velocity and Permeability

There is no correlation between side-by-side measurements of permeability with standpipes driven into the substrate and apparent velocity with permanent wells at 67 artificial redds in February 2001. A linear regression analysis of the common log of the permeability versus the apparent velocity at 50 artificial redds in project sites produced a model with an adjusted-R^2 of 0.014 and a probability of 0.196. Another analysis for 17 artificial redds in the control sites produced a model with an adjusted-R^2 of 0.074 and a probability of 0.153. Figure 8 shows these relationships.

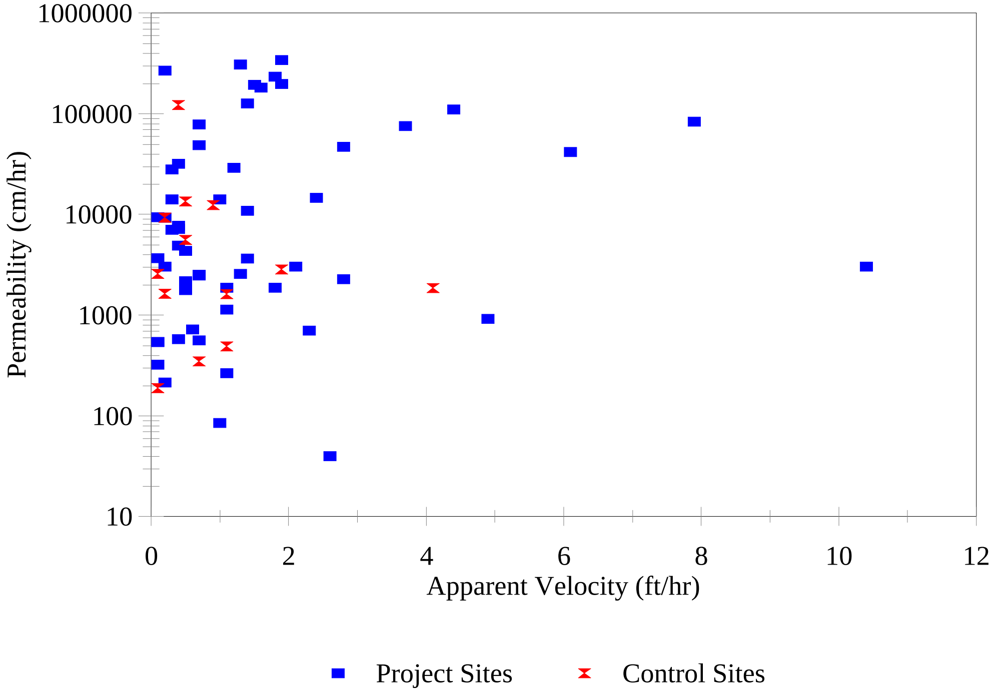

Figure 8. Scatter plot of side-by-side measurements of permeability on a common log scale versus apparent velocity in 50 artificial redds in project riffles and 17 artificial redds in control riffles in the Stanislaus River in February 2001.

There are several factors that probably contributed to the poor relationship between the measurements of permeability and apparent velocity at the artificial wells. First, driving the standpipe into the gravel would greatly affect bed permeability whenever the standpipe encounters large stones that must be pushed out of the way as the pipe is driven into the bed. It is difficult, if not impossible, to determine when large rocks are encountered because driving the standpipe into the streambed was equally hard to do in highly cemented beds with small stones as compared to pushing large stones out of the way. Second, artificially high permeabilities would also result from pumping fines from the streambed during the permeability measurement. It is likely that both pumping fines from the streambed and moving large rocks while driving a standpipe into the streambed could create a channel of high permeability surrounding the standpipe through which surface water could be easily drawn down into the standpipe. This would explain why high permeabilities were measured at some artificial redds where low apparent velocities were also measured (Figure 8). For example, at R78 P2 the permeability was measured at 269,860 cm/hr whereas the apparent velocity was only 0.2 feet/hour (Table 7 in Appendix 2). Coble (1961) and Phillips and Campbell (1962) also reported that apparent velocity and permeability were poorly correlated in artificial redds. For example, Coble measured a mean permeability of 35,500 cm/hr at an artificial redd where the mean apparent velocity was 0.16 feet/hour. Both Coble and Phillips and Campbell used the same standpipe to measure apparent velocity and permeability at each artificial redd and they did not drive the standpipes into the redds but instead buried the standpipes in the redds and then left them in place between measurements. Therefore, the unexpectedly high permeabilities during their studies must have been caused by pumping fines during the measurements.

Other factors that can affect apparent velocity measurements do not satisfactorily explain the poor correlation with permeability reported here. While differences in hydraulic gradient affect intragravel flow rates but not permeability, the estimated hydraulic gradient was similar among all the artificial redds and it was nearly identical among artificial redds measured during the same survey and within the same site where water depths and bed gradients were similar. For example, the water depth, bed gradient, and substrate composition were nearly identical between artificial redds R78 P2 and R78 P4, which was 30 feet directly downstream from R78 P2. As expected, the apparent velocities at these redds were nearly identical in February 2001 (Table 7 in Appendix 2); however, the permeability was 269,860 cm/hr at R78 P2 but only 28,187 cm/hr at R78 P4. The most likely explanation for the unusually high permeability measurement at R78 P2 is that the substrate was disturbed to a much greater degree at R78 P2 when the standpipe was driven into the streambed.

Although it is possible for the slots of the apparent velocity wells to become excessively clogged with fines in otherwise highly permeable substrates and thereby underestimate the true apparent velocity, there was no evidence that this occurred here. The wells were examined as they were retrieved and none had unusually high amounts of silt clogging their slots compared to the wells used to calibrate the meter.

Because the method of measuring permeability by driving standpipes into the streambed and then pumping water and fines from the standpipe probably overestimates the bed permeability at some but not all sites, the permeability measurements and predictions of egg survival to emergence based on these measurements should be considered as indices. Such indices would be suitable for comparisons, such as between project and control sites if the probability of encountering large stones was similar among the test groups. This is probably a safe assumption for this study because the particle size distributions were similar for the substrate samples collected at the control sites (CMC 2001a) and the restoration gravel added to the project sites (CMC 2001b), except that the restoration gravel contained fewer fines.

INTRAGRAVEL DISSOLVED OXYGEN CONCENTRATION

The intragravel D.O. concentrations declined slightly between the initial survey in mid October to late November, but thereafter they remained relatively constant through early February 2000. The mean D.O concentration was 94.4% of saturation for five restoration sites surveyed in mid October. It then declined to 92% of saturation for the early November survey, which is a significant ($P = 0.055$) difference based on a paired *t*-test of the same sites measured during the mid October survey. This decline corresponds to the 1,100-cfs pulse flow in late October, when apparent velocities declined as well. The mean D.O. concentration for all sites declined from 90.2% in early November to 87.4% in late November, which corresponds to the peak spawning period in the Stanislaus River when storm runoff is minimal. This difference is significant ($P = 0.0004$) based on a paired t-test. Thereafter, the mean D.O. concentration ranged between 87.4% and 88.8% through the early February survey. Similar to the fall 1999 results, the turbid storm runoff that occurred prior to the early February survey had no significant effect on the dissolved oxygen concentration in the artificial redds. The mean D.O. concentration observed in fall 2000 was higher than the 79.2% observed in December 1999.

There were no significant differences in the intragravel D.O. concentrations between the restoration sites and the control sites during the three December surveys, when chinook salmon eggs begin to hatch and their oxygen requirements are highest. The mean D.O. concentration in December was 88.1% (10.16 ppm) for 154 measurements at the restoration sites and 87.0% (10.08 ppm) for 56 measurements at the control sites (Figure 9). This difference was not significant (P = 0.105) based on a two-sample *t*-test.

Another analysis was made for the early February survey, because it is the end of the sensitive period for egg survival as most of the chinook salmon eggs have hatched and it would show the effect of fine sediment intrusion from the turbid storm runoff in late January. During the February survey, there was no significant difference between the mean D.O. concentration of 89.2% measured at 47 artificial redds in the restoration sites and the mean D.O. concentration of 88.0% measured at 18 artificial redds in the control sites based on a two-sample *t*-test.

The D.O. concentrations were usually greater than 8.0 ppm at almost every artificial redd (Table 8 in Appendix 2), which is probably adequate for 100% survival to hatching (CMC 2001b). However, D.O. concentrations were less than 8.0 ppm for extended periods at one artificial redd in a project site, R16 P1, and another artificial redd in a control site, R59 P3. A low concentration was also observed at R19 P4, which was in a restoration site, in early November; however, this artificial redd was subsequently destroyed by redd superimposition which prevented additional measurements. It is likely that egg mortality and stunted alevin growth would have occurred at these three artificial redds (CMC 2001b).

It is noteworthy that the D.O. concentration and apparent velocities measured in early February were poorly correlated. The adj-R^2 for a linear regression model was 0.073, although the model was significant (P = 0.017). In one case at R16 P1, the apparent velocity was relatively high at 5.5 feet/hour whereas the mean D.O. concentration was low at 6.9 ppm in December. Conversely, apparent velocities were less than 0.5 feet/hour at 21 artificial redds where the D.O. concentrations were high in February (Tables 7 and 8 in Appendix 2).

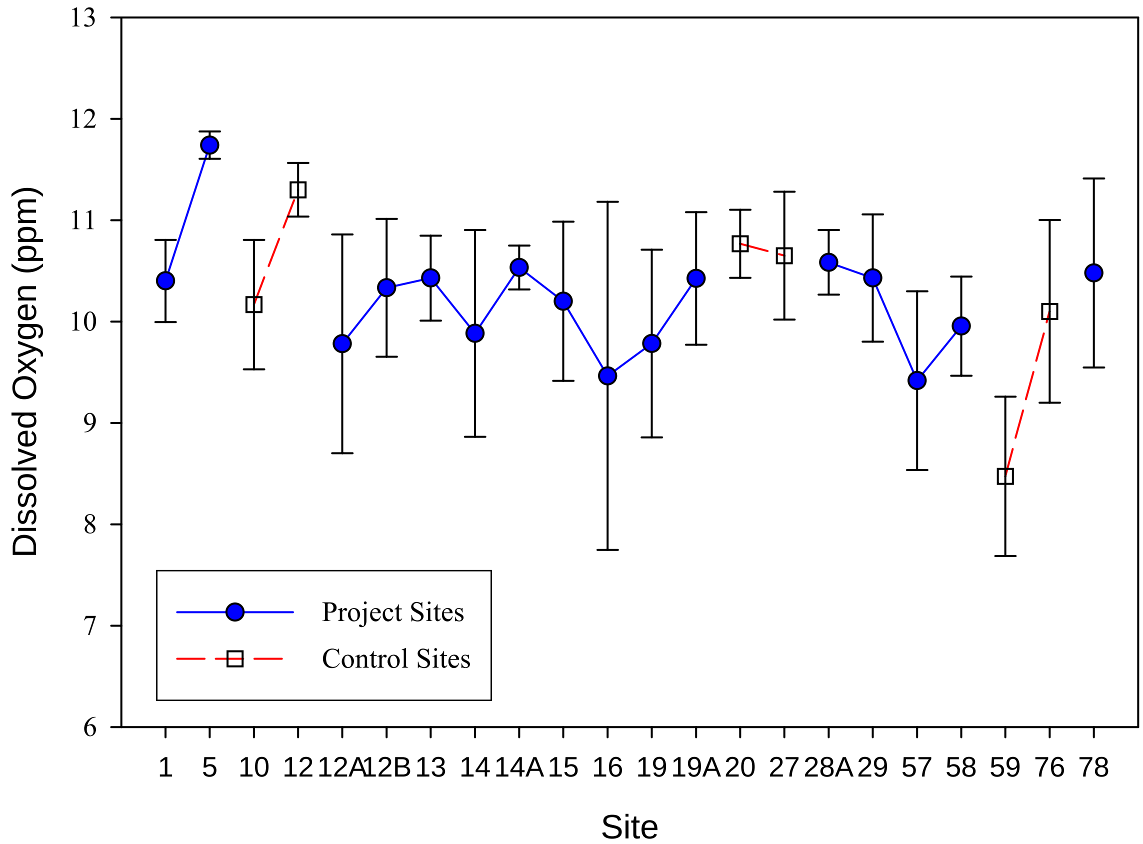

Figure 9. Scatter plot showing the mean intragravel dissolved oxygen concentration and standard deviation (error bars) at project and control sites in the Stanislaus River between Riffle R1 at the Knights Ferry Bridge and Riffle R78 near Oakdale.

VERTICAL HYDRAULIC GRADIENT

The vertical hydraulic gradient (VHG) was low at all sites in fall 2000 and there was no clear indication that the addition of clean gravel to the restoration sites affected upwelling or downwelling in the artificial redds with the piezometers (Table 9 in Appendix 2). The absolute value of the VHG was less than 0.066 at most piezometers during the early November, late December, and early February 2001 surveys, which indicates that the hydraulic head was usually 2 centimeters or less. The estimates declined significantly (P = 0.001) by an average difference of 0.016 between the November survey and the December survey based on paired t-tests, whereas, there was no significant change between the December and February surveys. VHG at the artificial redds surveyed in fall 1999 were similarly low.

The VHG routinely switched from positive readings, which indicate upwelling, to negative readings, which indicate downwelling, and vice versa between the three surveys at many of the artificial redds. VHG estimates tended to be positive during the early November survey whereas the number of negative estimates increased during the December and February surveys when streamflows declined from 350-cfs to 325-cfs and then to 300-cfs, respectively. The following table presents the percentage of VHG estimates that were either positive or negative; estimates of zero are not reported in this table.

	Early November		Late December		Early February	
	Positive	Negative	Positive	Negative	Positive	Negative
Project Sites	71.7%	15.1%	44.0%	32.0%	54.8%	28.6%
Control Sites	47.4%	26.3%	31.6%	42.1%	27.8%	61.1%
All Sites	65.3%	18.1%	40.6%	34.8%	46.7%	38.3%

The VHG was significantly different ($P = 0.033$) between the restoration sites and the control sites only during the February survey based on two-sample *t*-tests; the VHG for the artificial redds in the control sites was -0.024 lower than for those in the project sites. Although these results suggest that downwelling occurred more frequently at the control sites than at the project sites in February and to a lesser degree during the November and December surveys, the greater frequency of downwelling did not result in elevated dissolved oxygen concentrations at the control sites compared to the project sites.

INTRAGRAVEL WATER TEMPERATURE

Intragravel and surface water temperatures were measured to provide an index of downwelling rates of surface flow. Presumably if downwelling rates are high, then the magnitude and fluctuation of the intragravel water temperatures should be nearly identical to those of the surface. The only normal difference between surface and intragravel temperatures in highly permeable gravel is that intragravel water temperatures tend to lag behind surface temperatures by one to two hours. In contrast, when fine sediments accumulate in redds, downwelling rates would be reduced and the proportion of groundwater that upwells into a redd would increase. If the rate of groundwater upwelling is substantial, then the intragravel water temperatures would be relatively high and stable compared to surface temperatures. Groundwater upwelling in the redd would also result in low D.O. levels (McNeil 1969, Leitritz and Lewis 1980). A previous study in the Stanislaus River in fall 1995 indicates that groundwater upwelling increased and D.O. levels substantially declined immediately following a substantial pulse in flow from storm runoff (Mesick 2001a). A subsequent study in the Stanislaus River in fall 1996 determined that low D.O. levels occurred at artificial redds where intragravel water temperatures were relatively high and stable prior to any storm flow pulse (CMC 1997). The purpose of using an index based on differences in intragravel and surface water temperatures is to determine the timing and magnitude of groundwater upwelling. Knowledge of the timing and magnitude of groundwater upwelling should help determine the effects of various sources of fine sediment such as redd superimposition, turbid storm runoff, and high flow releases from New Melones Reservoir on intragravel water conditions in restoration gravel versus natural gravel.

The magnitude and fluctuation in intragravel water temperatures were nearly identical to those of the surface water at 79% (57/72) of the recovered piezometers from the time they were buried between 25 September and 13 October 2000 until early February 2001 when they were retrieved. As examples of these sites, the data from the surface thermographs and the thermographs buried at piezometers R1 P4, R5 P1, R14A P1, R20 P1, R29 P1, R57 P2, R58 P4, R76 P1, and R78 P1 are plotted in Appendix 5. Minor differences between the two sets of measurements should not be considered to be significant because the *StowAway TidbiT* has a temperature accuracy of $\pm$ 0.36 degrees Fahrenheit and an error in the time function that is as much as one hour per year (Onset 1998).

The intragravel water temperatures were relatively stable compared to the surface water temperatures at eight piezometers and they were elevated by 0.5 to 5.4 degrees Fahrenheit at seven other piezometers (Table 10 in Appendix 2 and plots in Appendix 5). The intragravel dissolved oxygen concentration, apparent velocity, and permeability at the artificial redds in December 2000 and February 2001 were significantly lower at the piezometers with elevated and to a lesser degree stable water temperatures than at the piezometers where there were no temperature deviations.

- The mean intragravel dissolved oxygen concentration at the seven piezometers with elevated temperatures was 77.4% of saturation, which is significantly lower (P = 0.037) than the mean of 85.2% of saturation for the eight piezometers with stable intragravel temperatures based on a two-sample *t*-test. The mean dissolved oxygen concentration for both the piezometers with elevated and stable temperatures are significantly lower than the mean of 89.7% for the piezometers where no temperature deviations occurred.
- The mean apparent velocity at the seven piezometers with elevated temperatures was 0.84 feet/hour, which is significantly lower (P = 0.000) than the mean of 2.45 feet/hour for the piezometers where no temperature deviations occurred based on a two-sample *t*-test. The mean apparent velocity at seven piezometers with stable temperatures was 1.74 feet/hour, which might be significantly greater (P = 0.088) than those with elevated temperatures but not significantly different (P = 0.201) from those with no temperature deviations.
- The mean permeability at seven piezometers with stable temperatures was 9,602 cm/hour, which is significantly lower (P = 0.003) than the mean of 47,891 cm/hour for those with no temperature deviations. However, the mean permeability at seven piezometers with elevated temperatures, which was 59,283 cm/hour, was not significantly different from those without temperature deviations (P = 0.707) or those with stable temperatures (P = 0.243). It is likely that the unusually high permeabilities that occurred at two piezometers with elevated temperatures, R58 P3 and R78 P2, were caused by disturbing the substrate while driving in the permeability standpipe prior to the measurement (see the Substrate Permeability section for a discussion of this problem).

Deviations in the intragravel water temperatures did not always correlate well with low apparent velocity or low intragravel dissolved oxygen concentrations. Apparent velocity was low, less than 1.0 feet/hour, at 21.1% (12/57) of the piezometers where no temperature deviations occurred. Similarly, dissolved oxygen concentrations were relatively low, less than 85% of saturation, at 17.5% (10/57) of the piezometers where no temperature deviations occurred. Conversely, the apparent velocities and dissolved oxygen concentrations were relatively high, above 2 feet/hour or 87% of saturation, at 21.4% and 26.7% respectively at piezometers with either stable or elevated temperatures.

The correlations between low dissolved oxygen concentrations and elevated temperatures were stronger in fall 1999 than in fall 2000. In fall 1999, dissolved oxygen concentrations ranged between 55.9% and 69.2% (mean 63.6%) of saturation at five piezometers where the intragravel water temperatures were elevated by at least one degree Fahrenheit (CMC 2001b). In contrast, the mean D.O. concentration was 76.6% of saturation for five piezometers also elevated by at least one degree Fahrenheit during fall 2000. Dissolved oxygen concentrations were consistently below 75% of saturation during both the fall 1999 and fall 2000 studies, when intragravel water temperatures were elevated by more than 2 degrees Fahrenheit.

The elevated or stable intragravel water temperatures and low dissolved oxygen concentrations usually began during the late October 2000 pulse flow of 1,100-cfs, whereas temperature deviations were not associated with the turbid storm runoff in January (Table 10 in Appendix 2). High flow releases of 1,500-cfs made for flood control in mid February 2000 also resulted in slight ($\leq$ 0.5 F) elevations in intragravel water temperatures (CMC 2001b) at 44% (19/43) of the artificial redds. These results suggest that fine sediment intrusion that occurs during high flow releases of at least 1,500 cfs from Goodwin Dam degraded incubation habitat to a greater degree than resulted from the turbid storm runoff that occurred in January 2001 or January 2000, when intensive rain storms produced up to 855 cfs of turbid runoff (CMC 2001b). However, elevated water temperatures that were correlated with the late October pulse flow were detected at only five of the 72 piezometers in fall 2000.

Other factors, such as the intragravel transport of fines in silty riffles during normal flow releases, fine sediment intrusion from nearby redd construction, and unusually high groundwater inflow rates probably affected intragravel water temperatures at 66.7% (10/15) of the piezometers with temperature deviations. Unusually high groundwater inflow rates would explain the temperature deviations at piezometers R20 P2 and R29 P4, where apparent velocities were consistently high. Intragravel transport of fines probably occurred at piezometers R14 P1, R57 P1, R59 P3, R78 P3, and R78 P4, because the temperature deviations began before the October pulse flow and redd construction and these riffles are relatively silty. Nearby redd construction might be the best explanation for the temperature deviations that occurred at R1 P1 and R58 P3, because the temperature deviations began during the primary spawning period.

ALEVIN ENTOMBMENT

A greater percentage of superimposed redds had dead alevins and eggs than were observed at non-superimposed redds. When the 19 superimposed redds were partially excavated to retrieve the piezometers in early February 2001, between 10 and 200 entombed alevins were observed at 31.6% (6 of 19) of the redds (Table 11 in Appendix 2). At one superimposed redd near artificial redd R20 P3, approximately half of the entombed alevins were still alive but in a highly emaciated condition. Since only the margins of these redds were excavated, it is likely that the true number of superimposed redds with entombed alevins and the number of entombed alevins in each redd were probably much higher than reported above. In contrast, entombed alevins were not observed at any of the five non-superimposed redds that were fully excavated at riffle R19A, a project site, and at only two of seven non-superimposed redds that were fully excavated at riffle R20, a control site. Combining the results from riffles R19A and R20, only 16.7% (2 of 12) of the non-superimposed redds contained entombed alevins. The number of entombed alevins was also relatively low at the non-superimposed redds at riffle R20: Only one dead alevin was observed at one redd and approximately 50 dead and 10 highly emaciated alevins were observed at the other.

CONCLUSIONS

The results of the fall 2000 studies suggest that adding clean gravel to restore spawning habitat may increase the survival of chinook salmon eggs to emergence in the Stanislaus River primarily by increasing the amount of available habitat and thereby reducing the number of eggs killed and alevins entombed by redd superimposition. Redd superimposition was commonly observed in the primary spawning reach in the Stanislaus River between Goodwin Dam and Willms pond during fall 2000 and in previous studies (Mesick 2001a; CMC 2001b). It is likely that the gravel and gold mining that occurred in the active channel of the Stanislaus Gravel between the 1930s and 1970s substantially reduced the availability of spawning habitat and thereby caused high rates of redd superimposition by crowding the spawners (Mesick 2001b). Between 1949 and 1999, which is after the peak mining period during the early 1940s (P. Frymire, personal communication, see "Notes"), Kondolf et al. (2001) estimated that 1,031,800 yd^3 of gravel were extracted from the active channel between Goodwin Dam (RM 58.5) and Oakdale (RM 40). The Knights Ferry Gravel Replenishment Project added a total of 13,000 tons of gravel to the streambed and so only a small fraction of the historical spawning habitat in the Stanislaus River has been restored.

The KFGRP studies also provided valuable information regarding the restoration of spawning habitat for chinook salmon. The Task 5 Fall 1999 studies demonstrated that fall-run chinook salmon will spawn immediately at the tails of pools constructed with newly placed gravel (CMC 2001b). In addition, redd densities were found to be significantly higher in gravel obtained from the Stanislaus River's floodplain compared to similarly-sized gravel imported from the Tuolumne River's floodplain during both fall 1999 and fall 2000. The relative density of redds increased at the sites with Tuolumne River rock in fall 2000 compared to the redd densities at the control sites providing evidence that restoration gravel rapidly "seasons". It is possible that seasoning occurs as minerals dissolve from the gravel's surface, which diminishes the intensity of the odor of foreign rock over time. Although the mineral content of the two sources of gravel was not determined, the Stanislaus River gravel and Tuolumne River gravel differed in color and presumably mineral content and it is likely that the salmon could smell these differences. If true, chinook salmon tend to select spawning sites in gravel that matches the odor of the gravel where they incubated as alevins and reared as juveniles.

Redd densities were also higher, although not significantly, in Stanislaus River gravel cleaned with a 1/4-inch screen than in the gravel cleaned with a 3/8-inch screen in fall 1999, whereas the redd densities were nearly identical between these two groups of riffles in fall 2000. One explanation for the relative increase in redd density in the gravel cleaned with a 3/8-inch screen in fall 2000 is that the intrusion of fine sediment during summer 2000 added sand that provided "lubrication" which facilitated the digging of salmon redds. Salmon frequently construct redds at artificial redd sites, where the construction of the artificial redd in the cemented streambed would have loosened the gravel and facilitated subsequent redd construction. It was also noticeably easier to dig artificial redds with hoes and shovels in the gravel washed with the 1/4-inch screen than in the gravel washed with a 3/8-inch screen. If substrate particles between 1/4 and 3/8-inches act as a "lubricant" during redd construction, then seasoning may result from the intrusion of fine sediment.

One recommendation for future studies is to directly measure egg survival to emergence by planting eggs to determine the percentage of eggs that survive to hatching and also by determining emergence rates in natural redds, both at single and superimposed redds. A critical review of the literature on salmonid egg survival to emergence indicates that it is difficult to accurately estimate the percentage of salmonid eggs that survive to emergence based on habitat measurements, such as intragravel D.O. concentrations, apparent velocity, permeability, and the concentration of substrate fines (CMC 2001b). Comparisons among previous field and laboratory studies suggest that egg survival to hatching is substantially affected by the adhesion of fine sediment to the egg's membranes although this presumed influence has not been quantified. Furthermore, studies of alevin emergence rates have either used abnormally healthy alevins tested under laboratory conditions or failed to accurately estimate the initial number of viable eggs or the number of alevins that escaped from natural redds capped with netting, which makes it impossible to determine the accuracy of the egg survival to emergence estimates. Intragravel D.O. concentrations, apparent velocity, and water temperature should be monitored relative to egg survival and emergence to help develop a model that could be used to accurately predict egg survival based on habitat measurements. The turbidity of intragravel water should also be monitored to try to establish an index of the amount of fines adhering to egg membranes. Permeability measurements could be made at some lots of planted eggs by installing a permanent standpipe. However, pumping substrate fines from the artificial redds during measurements may confound the results. Furthermore, there may be few benefits from permeability measurements because previous studies suggest that permeability may not be well correlated with egg survival (CMC 2001b).

Valuable information was also provided on two methods of evaluating intragravel conditions for egg incubation. The method of driving a standpipe into the substrate to estimate permeability appears to be unreliable for two reasons. First, driving the standpipe into the substrate would greatly affect bed permeability whenever the standpipe encounters large stones that must be pushed out of the way. Second, pumping water and fines out of the standpipe to estimate permeability probably creates a channel of high permeability surrounding the standpipe that would result in an artificially high reading. These two problems would explain the poor correlations observed between side-by-side measurements of permeability and apparent velocity during this study and studies conducted by Coble (1961) and Phillips and Campbell (1962). In contrast, the method of using deviations in intragravel water temperatures in artificial redds from surface water temperatures was useful because it helped demonstrate that high rates of fine sediment intrusion and upwelling of oxygen-poor groundwater primarily coincided with managed pulse flows of at least 1,100 cfs. Other factors probably associated with fine sediment intrusion in artificial redds include the intragravel transport of fines in silty riffles during normal flows and nearby redd construction. The temperature measurements also demonstrated that a majority of the problems associated with the upwelling of oxygen-poor groundwater occurred in the downstream sites where few salmon spawn.

HYPOTHESIS TESTING

The evidence provided by the fall 2000 studies regarding the 10 hypotheses identified in the Ecological Monitoring Plan (CMC 1999b) is summarized below.

Hypotheses on Improving Spawning Habitat

Hypothesis I-A: The density of fall-run chinook salmon redds will be higher in unconsolidated gravel in the project riffles than in the cemented gravel in the control riffles.

The density of redds was significantly greater at project riffles with Stanislaus River rock cleaned with a 3/8-inch screen and at the sites with Tuolumne River rock than at the control riffles in fall 2000. Although the redd densities at the project riffles with Stanislaus River rock cleaned with a 1/4-inch screen were substantially higher than those at the control riffles, it was not possible to statistically test this comparison.

Redd densities increased at the project sites, particularly those with Stanislaus River rock cleaned with a 3/8-inch screen and Tuolumne River rock in fall 2000 compared to fall 1999. In fall 1999, redd densities at the control sites may have been significantly greater ($P = 0.096$) than at the sites with Tuolumne River rock but not significantly different ($P = 0.483$) from the densities at the sites with Stanislaus River rock cleaned with a 3/8-inch screen. The increase in relative spawner use at the restoration sites in fall 2000 suggests that the restoration rock had "seasoned" during the first 12 months after placement in the river such that the gravel became more attractive to spawning salmon.

> Hypothesis I-B: The higher the elevation of a riffle's crest, the greater will be the rate of surface water downwelling that presumably helps attract spawners.

The elevation of the natural riffle's crest as measured under pre-project conditions was not correlated with the density of redds or with the downwelling rates and apparent velocity in artificial redds. A linear regression analysis indicated that the bed gradient of the natural riffle's crest was not significantly correlated with either the vertical hydraulic gradient in November 2000 ($P = 0.709$), which is the measurement of downwelling rate used in this study, or the mean apparent velocity in November and December 2000 ($P = 0.134$). A stepwise linear regression analysis indicated while redd density in the project sites was strongly correlated with distance downstream (adj-$R^2 = 0.648$; $P = 0.0001$), other variables such as bed gradient ($P = 0.621$), mean vertical hydraulic gradient in November ($P = 0.996$), and the mean apparent velocity in November and December ($P = 0.302$) were excluded from the model. These analyses and the fall 1999 data (CMC 2001b) suggest that equally suitable spawning habitat can created by adding gravel to extensively mined channels, naturally flat channels, or preferred natural spawning sites at the tails of pools.

Hypotheses on Improving Incubation Habitat

Chinook salmon are able to create suitable egg incubation conditions by cleaning the fines from the substrate during redd construction in both restoration and natural riffles as indicated by the permeability measurements chinook salmon redds in fall 1999 and fall 2000. Egg and alevin mortality in the Stanislaus River is probably most affected by turbid storm runoff that coats the eggs with a suffocating layer of clay-sized particles and redd superimposition that completely destroyed or disturbed 24% of the artificial redds constructed in fall 2000 thereby killing most of the eggs and buried another 23% of the artificial redd with gravel and fines that would entomb some or all of the alevins. Turbid storm runoff was a minor problem in fall 2000 as storm runoff was minimal and did not occur until late January 2001. Redd excavations suggest that the entombment of alevins by redd superimposition may be a substantial problem in the Stanislaus River. However, further study is needed to quantify mortality due to entombment.

Hypothesis II-A: Adding gravel without fines to the streambed increases intragravel flow in redds.

Three indices of intragravel flow each suggest that the intragravel flow in redds was higher in project sites than in control sites in fall 2000. One index, permeability measurements in chinook salmon redds, indicated that bed permeability in the vicinity of the egg pocket is significantly greater in the project sites than in the control sites. The predicted egg survival based on the permeability measurements is 61.8% for the project sites, which is significantly greater than the predicted survival rate of 48.1% for the control sites. A second index, apparent velocity measurements in artificial redds, indicated that the mean apparent velocity was greater in the project sites than in the control sites, although the differences were not statistically significant. The third index, deviations in the intragravel water temperature from the surface water temperature, indicated that the downwelling of surface flow decreased and the upwelling of oxygen-poor groundwater increased during the spawning period at 36.8% (7 of 19) of the artificial redds in control sites and at 15.1% (8 of 53) of the artificial redds in the project sites.

Although all three indices suggest that intragravel flows are more suitable for egg incubation in redds constructed in the project sites than in the control sites, the differences between the project and control sites may not be biologically meaningful. First, comparison of side-by-side measurements of apparent velocity and permeability indicates that driving a standpipe into the substrate to measure permeability occasionally disturbs the substrate and thereby results in artificially high estimates. Furthermore, steelhead trout and coho salmon egg survival to hatching in natural streams has not been correlated with permeability (Coble 1961; Phillips and Campbell 1962).

Second, although apparent velocities were generally higher in artificial redds in project sites than in control sites, they were probably high enough to support high rates of egg survival in both control and project sites. The minimum apparent velocity that maintains high rates of egg survival ranges between 0.52 and 1.52 feet/hour based on studies by Gangmark and Bakkala (1960), Coble (1961), and Phillips and Campbell (1962); see CMC (2001b) for a discussion of these studies. It is likely that the apparent velocities in chinook salmon redds during the primary incubation period between early November and late January would be similar to the relatively high measurements, which ranged between 1.1 and 17.8 feet/hour, that were measured in artificial redds at five project sites in mid October 2000 prior to the late October pulse flow. All of the artificial redds were constructed prior to the October pulse flow and the pulse flow probably caused high rates of fine sediment intrusion that caused the apparent velocity to decline from a mean of 6.0 feet/hour in mid October to a mean of 2.1 feet/hour in early November. Since the apparent velocities in the artificial redds changed little between the early November survey and the late December survey, it is likely that redds constructed after the October pulse flow, as were most of the chinook salmon redds, would have a mean apparent velocity of about 6 feet/hour and few would have apparent velocities below 1.5 feet/hour at least until the turbid storm runoff occurred in late January and early February.

Third, fine sediment intrusion and upwelling of oxygen-poor groundwater that was indicated by deviations in intragravel water temperature from surface water temperatures primarily occurred in the downstream sites near the Valley Oak Recreational Park (riffles R57, R58, and R59) and the Oakdale Recreational Park (riffles R76 and R78) where few salmon spawn. Only about 6% of the total number of redds observed occurred at these downstream sites and so the consequences to the population are probably minimal.

> Hypothesis II-B: Higher gradients of the streambed upstream of the hydraulic control at the riffle's crest result in higher rates of surface water downwelling that presumably increases intragravel dissolved oxygen concentrations.

All of the project riffles were created with bed gradients that sloped upward like the tail of a pool and so this hypothesis cannot be evaluated with fall 2000 data. Future evaluations might be appropriate, if high flows alter the bed gradient of some riffles, but not others.

> Hypothesis II-C: The low percentage of fines in the project riffles will result in high intragravel D.O. concentrations relative to those at the control riffles, where the concentration of fines is high.

The intragravel D.O. concentrations in artificial redds were not significantly different between the project and control sites in December 2000, when the eggs began to hatch, or in early February 2001, after most of the eggs have hatched. The D.O. concentrations were usually greater than 8.0 ppm at almost every artificial redd, which is probably optimum for egg survival (CMC 2001b). However, D.O. concentrations were less than 8 ppm for extended periods at one artificial redd in a project site and another in a control site. Low concentrations were also observed at one artificial redd in a project site, but it was destroyed by redd superimposition in November 2000. It is likely that egg mortality and stunted alevin growth would have occurred at these three redds. D.O. concentrations were significantly higher in the project sites than in the control sites in fall 1999 (CMC 2001b), but not in fall 2000 probably because fine sediment intrusion rates were high at many of the sites during high flows in spring 2000 (CMC 2001b).

Hypotheses on the Size and Source of Restoration Gravel

> Hypothesis III-A: Restoration gravel obtained from near the Stanislaus River will be used by more Stanislaus River chinook salmon than will gravel obtained from another watershed.

Redd densities at restoration sites with Stanislaus River rock washed with a 3/8-inch screen were about 41% higher than the redd densities at nearby restoration sites where similarly sized Tuolumne River rock was added; the difference was significant ($P = 0.018$) based on a F-test that compared the elevations (intercepts) of the regressions of redd density versus distance downstream. There was a similar difference in fall 1999 that was moderately significant ($P = 0.073$). Presumably most chinook salmon in the Stanislaus River tend to select spawning sites in Stanislaus River rock because the gravel's odor matches the odor of the gravel where they incubated as eggs and reared as juveniles.

> Hypothesis III-B: Restoration gravel between 3/8 inch and 5 inches will produce higher gravel permeabilities than will gravel between 1/4 inch and 5 inches.

There were no statistically significant differences ($P \geq 0.692$) in the bed permeability in fall 2000 between the project sites with gravel washed with the 1/4-inch and 3/8-inch screens. The fine sediment intrusion that occurred in spring 2000 probably eliminated the differences observed between these two types of gravel in fall 1999 (CMC 2001b).

Hypothesis III-C: Restoration gravel between 1/4 inch and 5 inches will attract more spawners than will gravel between 3/8 inch and 5 inches.

The mean redd densities were nearly identical at riffles with Stanislaus River rock cleaned with a 1/4-inch screen and those with Stanislaus River rock cleaned with a 3/8-inch screen. An *F*-test indicated that neither the slopes ($P = 0.770$) nor the elevations ($P = 0.778$) of the regressions of redd densities versus distance downstream from Goodwin Dam were statistically different. While it is possible that the density of redds was slightly higher at the riffles with gravel cleaned with a 1/4-inch screen than at those with gravel cleaned with a 3/8-inch screen in fall 1999 (CMC 2001b), the fine sediment intrusion that occurred during spring 2000 seems to have improved the suitability of the gravel cleaned with a 3/8-inch screen in fall 2000 possibly because the fines provided a lubricant that facilitated redd construction.

Hypotheses on Fluvial Geomorphic Performance

Hypothesis IV-A: During high flows, high-crested riffles retain more gravel than moderate-crested riffles, which retain more gravel than low-crested riffles.

A bed mobility analysis for project riffles R1, R5, R28A, and R78 by Kondolf et al. (2001) suggests that flows between 5,000 to 8,000 cfs are necessary to mobilize the median diameter of the channel bed material. Flows of 5,000 cfs and 7,350 cfs would be expected to occur approximately every 3.4 and 22 years, respectively (Kondolf et al. 2001).

During spring 2000, flow releases from Goodwin Dam ranged between 3,000 and 3,500 cfs from 28 February and 9 March and between 1,300 and 1,500 cfs between 13 April and 12 June. These are relatively average flows for the post-New Melones Dam period (1979-present), during which flow of 3,070 cfs would have a 50% probability of occurring in a given year (Kondolf et al. 2001). Gravel movement primarily occurred at only four of the 18 project riffles during spring 2000. The pre-project gradient of the bed upstream of the natural riffle's crest was not significantly correlated with the volume of gravel moved in the project sites. Further evaluations of this hypotheses should be made after flows exceed 5,000 cfs.

Hypothesis IV-B: Project riffles in mined channels will lose gravel at a faster rate than will project riffles adjacent to functional floodplains.

This hypothesis was rejected for the flows up to 3,500 cfs that occurred in spring 2000. The mean volume of gravel mobilized from riffles that were adjacent to small but functional floodplains was 0.254 cubic yards of mobilized gravel per square yard of riffle area. This was not significantly larger ($P = 0.134$) than the mean of 0.099 cubic yards of mobilized gravel per square yard of riffle area estimated for the sites without adjacent floodplain habitat. Gravel movement may have been greater at the sites with functional floodplain because the bed shear stress at flows of 3,500 cfs was probably lower in the channels widened by gravel mining than at the relatively narrow unmined sites that were adjacent to floodplain habitat. Another factor is that two of the four sites with functional floodplains also contained unusual hydraulic controls, such as a large, horizontally growing tree and a bridge pillar, that created localized high rates of scour. Further evaluations are needed to determine whether floodplains have the expected effect at flows that exceed 5,000 cfs.

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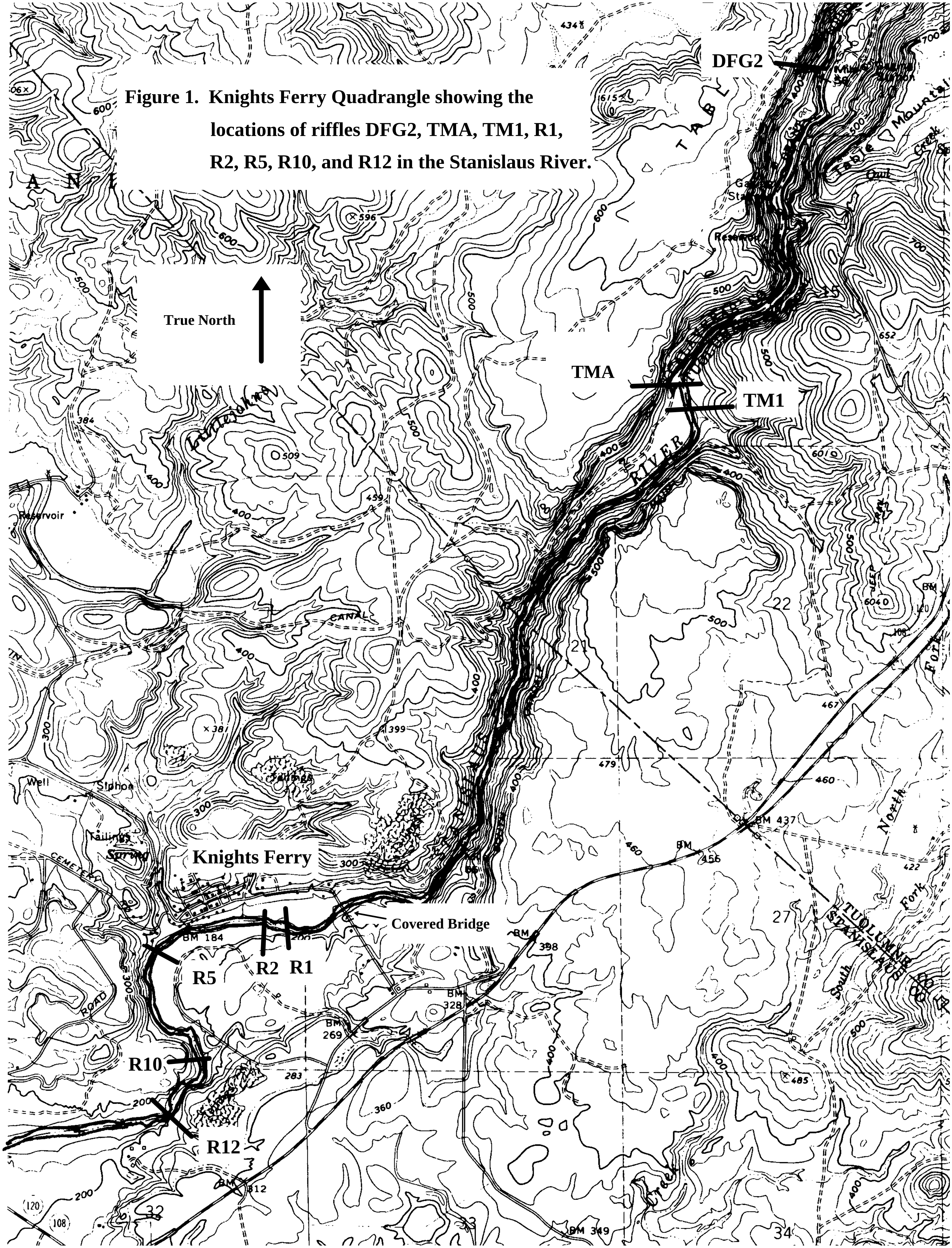
APPENDIX 1

USGS QUADRANGLES SHOWING SITE LOCATIONS

Figure 1. Knights Ferry Quadrangle showing the locations of riffles DFG2, TMA, TM1, R1, R2, R5, R10, and R12 in the Stanislaus River.



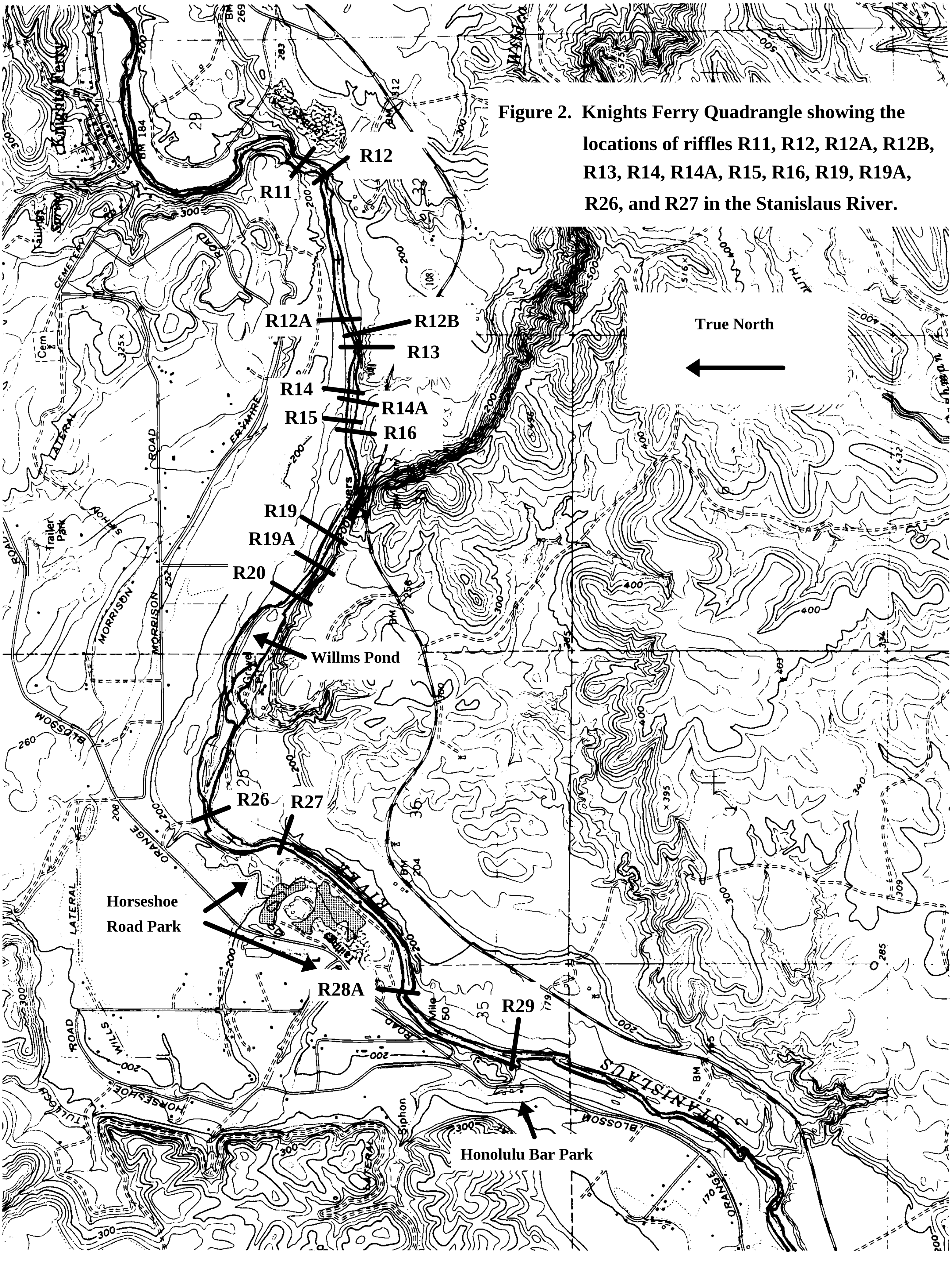


Figure 2. Knights Ferry Quadrangle showing the locations of riffles R11, R12, R12A, R12B, R13, R14, R14A, R15, R16, R19, R19A, R26, and R27 in the Stanislaus River.

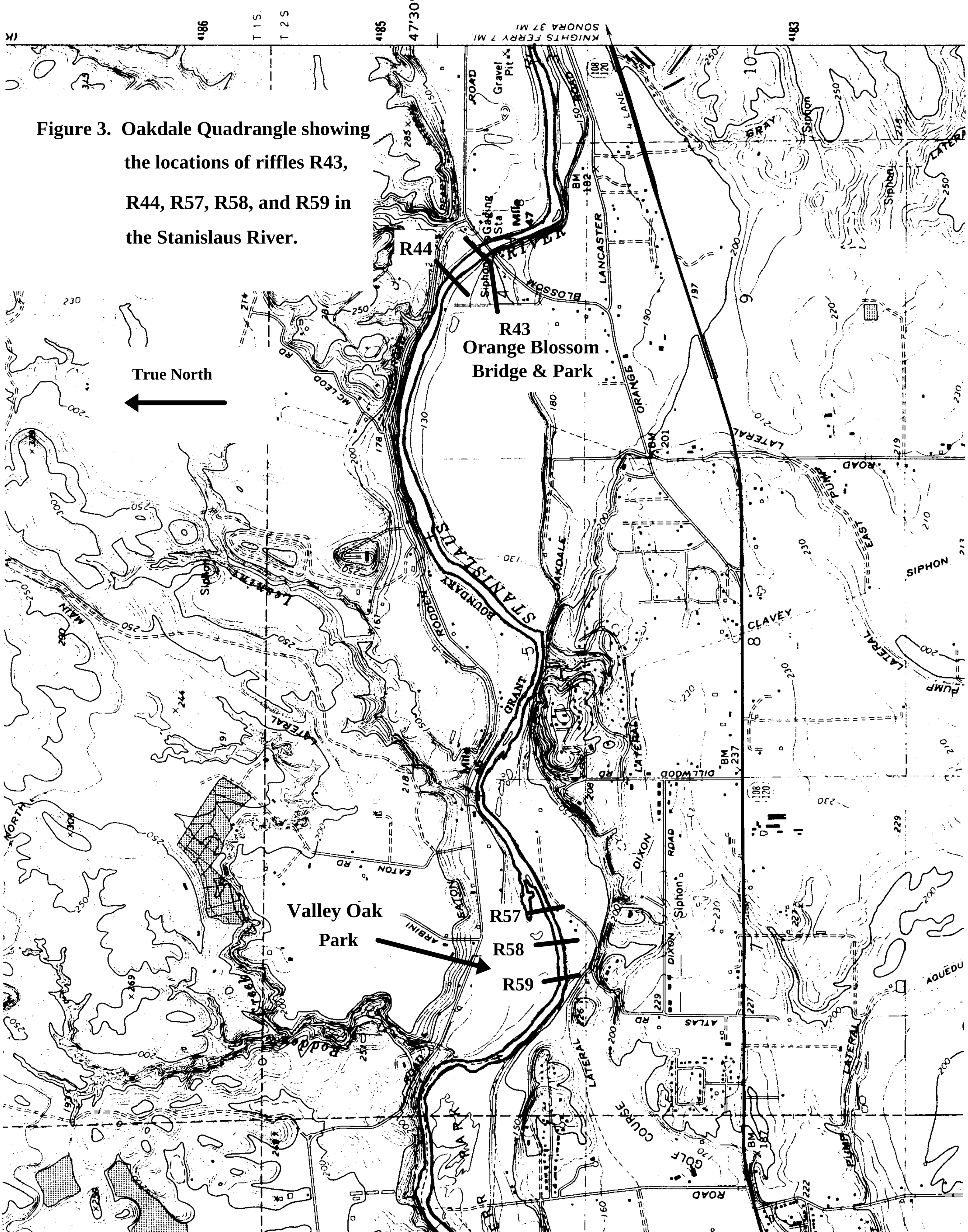


Figure 3. Oakdale Quadrangle showing the locations of riffles R43, R44, R57, R58, and R59 in the Stanislaus River.

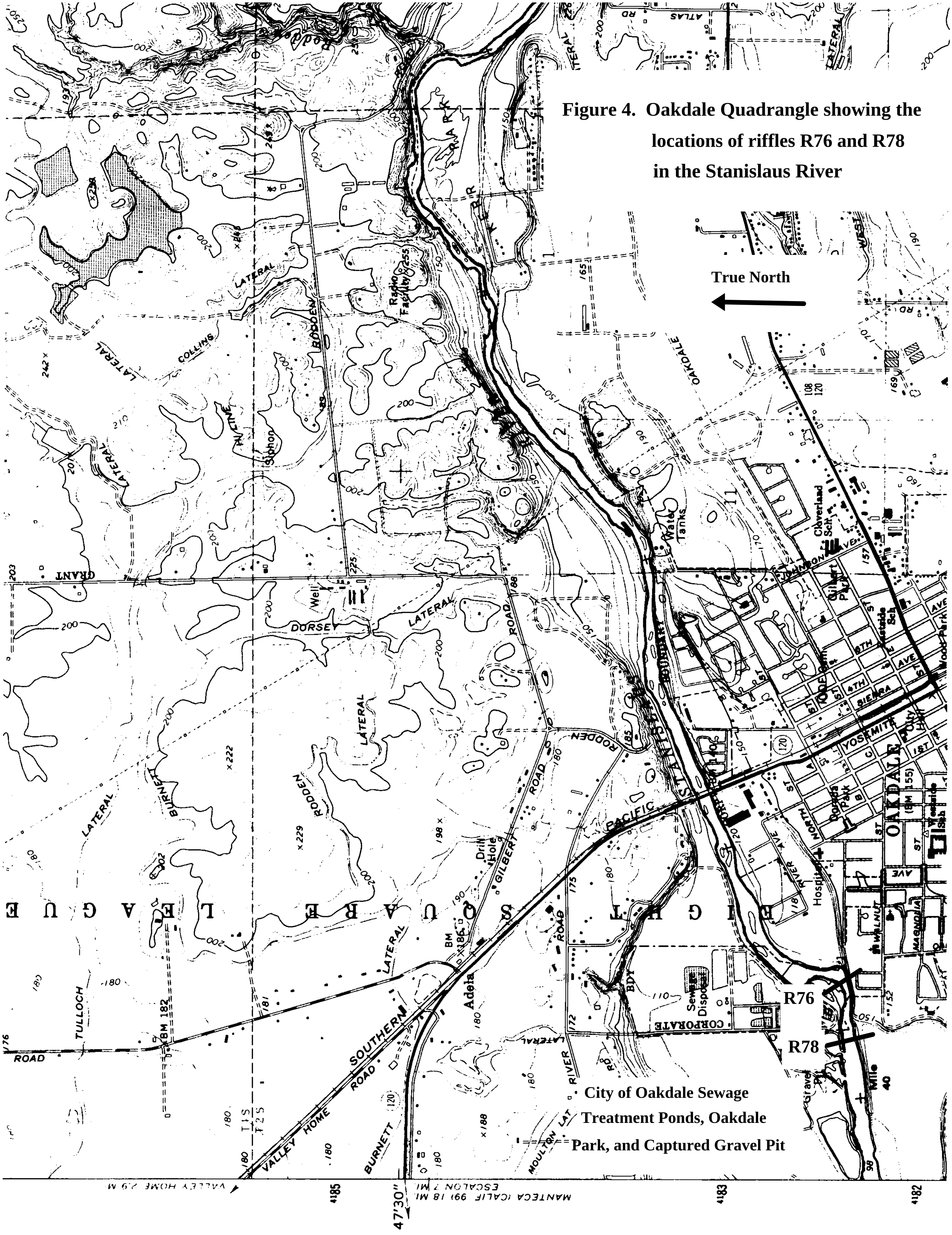


Figure 4. Oakdale Quadrangle showing the locations of riffles R76 and R78 in the Stanislaus River

APPENDIX 2

Tables 1-11 of Results

Table 1. The rivermile and streambed gradient upstream from the riffle's crest of the riffles selected for the Knights Ferry Gravel Replenishment Project in the Stanislaus River and the amount of gravel placed at the 18 project riffles in August and September 1999. The seven control riffles were not altered.

A) High-Crested Riffles (Tails of Deep Pools), 3.4% to 17.7% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
TMA	56.8	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	470	6.9%
TM1	56.6	Control Riffle, No Gravel Added	--	--	4.3%
R1	54.55	Stanislaus River-Rock, 3/8 to 5 inch diameter	550	395	10.5%
R12	53.3	Control Riffle, No Gravel Added	--	--	3.4%
R14A	52.57	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,430	1,055	5.4%
R28A	50.2	Stanislaus River-Rock, 1/4 to 5 inch diameter	450	250	5.2%
R29	49.75	Tuolumne River-Rock, 3/8 to 5 inch diameter	300	210	4.7%
R76	40.35	Control Riffle, No Gravel Added	--	--	17.7%
B) Moderate-Crested Riffles, 1.6 to 3% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R13	52.73	Stanislaus River-Rock, 3/8 to 5 inch diameter	1,200	860	1.7%
R15	52.51	Tuolumne River-Rock, 3/8 to 5 inch diameter	860	610	2.4%
R16	52.48	Tuolumne River-Rock, 3/8 to 5 inch diameter	330	240	2.8%
R20	51.8	Control Riffle, No Gravel Added	--	--	1.6%
R27	50.8	Control Riffle, No Gravel Added	--	--	2.9%
R43	46.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	2.0%
R58	44.5	Stanislaus River-Rock, 1/4 to 5 inch diameter	840	465	3.0%
R78	40.2	Tuolumne River-Rock, 3/8 to 5 inch diameter	570	405	2.5%
C) Low-Crested Riffles, 0 to 1.5% Streambed Gradient					
Riffle #	Rivermile	Gravel Type	Tons	Cubic Yd	Gradient
R5	53.9	Tuolumne River-Rock, 3/8 to 5 inch diameter	440	315	-0.4%
R10	53.5	Control Riffle, No Gravel Added	--	--	0.5%
R12A	52.82	Stanislaus River-Rock, 3/8 to 5 inch diameter	540	380	0.9%
R12B	52.77	Stanislaus River-Rock, 1/4 to 5 inch diameter	850	470	1.5%
R14	52.6	Stanislaus River-Rock, 1/4 to 5 inch diameter	835	465	1.3%
R19	52.13	Stanislaus River-Rock, 1/4 to 5 inch diameter	675	130	0.6%
R19A	52.06	Stanislaus River-Rock, 3/8 to 5 inch diameter	950	680	0.5%
R57	44.6	Stanislaus River-Rock, 3/8 to 5 inch diameter	900	645	0.1%
R59	44.4	Control Riffle, No Gravel Added	--	--	-0.5%

Table 2. Table for converting field inflow rate (ml/s) measurements in 0.1 increments to permeability (cm/hr).

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
2	80	110	120	150	160	170	175	180	185	190
3	195	210	220	230	240	250	260	270	280	285
4	290	305	310	320	330	340	350	360	370	380
5	390	405	415	430	440	450	465	475	485	490
6	500	505	515	530	540	550	565	575	585	590
7	600	605	615	630	640	650	665	675	685	690
8	705	710	720	730	740	750	765	785	795	800
9	810	815	825	835	845	850	860	870	880	885
10	890	905	920	935	950	960	970	980	990	1000
11	1100	1110	1120	1130	1140	1150	1160	1170	1180	1190
12	1200	1210	1220	1230	1240	1250	1260	1270	1280	1290
13	1300	1310	1320	1330	1340	1350	1360	1370	1380	1390
14	1400	1410	1420	1430	1440	1450	1460	1470	1480	1490
15	1500	1510	1520	1530	1540	1550	1560	1570	1580	1590
16	1600	1610	1620	1630	1640	1650	1660	1670	1680	1690
17	1700	1710	1720	1730	1740	1750	1760	1770	1780	1790
18	1800	1810	1820	1830	1840	1850	1860	1870	1880	1890
19	1900	1915	1930	1940	1950	1960	1970	1980	1990	2000
20	2020	2070	2100	2120	2140	2150	2160	2170	2180	2190
21	2200	2210	2220	2230	2240	2250	2260	2270	2280	2290
22	2300	2310	2320	2330	2340	2350	2360	2370	2380	2390
23	2400	2410	2420	2430	2440	2450	2460	2470	2480	2490
24	2500	2510	2520	2530	2540	2550	2560	2570	2580	2590
25	2600	2610	2620	2630	2640	2650	2660	2670	2680	2690
26	2700	2710	2720	2730	2740	2750	2760	2770	2780	2790
27	2800	2810	2820	2830	2840	2850	2860	2870	2880	2890
28	2900	2910	2920	2930	2940	2950	2960	2970	2980	2990
29	3000	3010	3020	3030	3040	3050	3060	3070	3080	3090
30	3100	3120	3140	3160	3180	3200	3220	3240	3260	3280
31	3300	3340	3380	3420	3450	3480	3510	3540	3560	3580
32	3600	3620	3640	3660	3680	3700	3720	3740	3760	3780
33	3800	3820	3840	3860	3880	3900	3920	3940	3960	3980
34	4000	4020	4040	4060	4080	4100	4120	4140	4160	4180
35	4200	4220	4240	4260	4280	4300	4320	4340	4360	4380
36	4400	4420	4440	4460	4480	4500	4520	4540	4560	4580
37	4600	4610	4620	4630	4640	4650	4660	4670	4680	4690
38	4700	4710	4720	4730	4740	4750	4760	4770	4780	4790
39	4800	4810	4820	4830	4840	4850	4860	4870	4880	4890
40	4900	4910	4920	4930	4940	4950	4960	4970	4980	4990

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
41	5100	5120	5140	5160	5180	5200	5220	5240	5260	5280
42	5300	5320	5340	5360	5380	5400	5420	5440	5460	5480
43	5400	5420	5440	5460	5480	5500	5520	5540	5560	5580
44	5500	5520	5540	5560	5580	5600	5620	5640	5660	5680
45	5600	5620	5640	5660	5680	5700	5720	5740	5760	5780
46	5700	5720	5740	5760	5780	5800	5820	5840	5860	5880
47	5800	5820	5840	5860	5880	5900	5920	5940	5960	5980
48	6000	6050	6100	6140	6180	6220	6260	6300	6340	6380
49	6400	6450	6500	6540	6580	6620	6660	6700	6740	6780
50	6800	6830	6860	6890	6920	6950	6980	7010	7040	7070
51	7100	7130	7160	7190	7220	7250	7280	7310	7340	7370
52	7400	7450	7500	7540	7580	7620	7660	7700	7740	7780
53	7800	7850	7900	7940	7980	8020	8060	8100	8140	8181
54	8200	8250	8300	8340	8380	8420	8460	8500	8540	8580
55	8600	8650	8700	8740	8780	8820	8860	8900	8940	8980
56	9000	9050	9100	9140	9180	9220	9260	9300	9340	9380
57	9400	9430	9460	9490	9520	9550	9580	9610	9640	9670
58	9700	9730	9760	9790	9820	9850	9880	9910	9940	9970
59	10000	10030	10060	10090	10120	10150	10180	10210	10240	10270
60	10300	10350	10400	10440	10480	10520	10560	10600	10640	10680
61	10700	10730	10760	10790	10820	10850	10880	10910	10940	10970
62	11000	11030	11060	11090	11120	11150	11180	11210	11240	11270
63	11300	11330	11360	11390	11420	11450	11480	11510	11540	11570
64	11600	11650	11700	11740	11780	11820	11860	11900	11940	11980
65	12000	12050	12100	12140	12180	12220	12260	12300	12340	12380
66	12400	12450	12500	12540	12580	12620	12660	12700	12740	12780
67	12800	12850	12900	12940	12980	13020	13060	13100	13140	13180
68	13200	13250	13300	13340	13380	13420	13460	13500	13540	13580
69	13600	13650	13700	13740	13780	13820	13860	13900	13940	13980
70	14000	14060	14120	14180	14240	14300	14360	14420	14480	14540
71	14600	14660	14720	14780	14840	14900	14960	15020	15080	15140
72	15200	15270	15340	15410	15480	15550	15620	15690	15760	15830
73	15900	15970	16140	16110	16180	16250	16320	16390	16460	16530
74	16600	16670	16740	16810	16880	16950	17020	17090	17160	17230
75	17300	17370	17440	17510	17580	17650	17720	17790	17860	17930
76	18000	18070	18140	18210	18280	18350	18420	18490	18560	18630
77	18700	18770	18840	18910	18980	19050	19120	19190	19260	19330
78	19400	19480	19560	19640	19720	19800	19880	19960	20040	20120
79	20200	20280	20360	20440	20520	20600	20680	20760	20840	20920
80	21000	21200	21400	21600	21800	22000	22200	22400	22600	22800

Table 2 (Continued)

(ml/s)	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
81	23000	23150	23300	23450	23600	23750	23900	24050	24200	24350
82	24500	24650	24800	24950	25100	25250	25400	25550	25700	25850
83	26000	26100	26200	26300	26400	26500	26600	26700	26800	26900
84	27000	27100	27200	27300	27400	27500	27600	27700	27800	27900
85	28000	28100	28200	28300	28400	28500	28600	28700	28800	28900
86	29000	29100	29200	29300	29400	29500	29600	29700	29800	29900
87	30000	30100	30200	30300	30400	30500	30600	30700	30800	30900
88	31000	31100	31200	31300	31400	31500	31600	31700	31800	31900
89	32000	32100	32200	32300	32400	32500	32600	32700	32800	32900
90	33000	33300	33600	33900	34200	34500	34800	35100	35400	35700
91	36000	36300	36600	36900	37200	37500	37800	38100	38400	38700
92	39000	39100	39200	39300	39400	39500	39600	39700	39800	39900
93	40000	40100	40200	40300	40400	40500	40600	40700	40800	40900
94	41000	41100	41200	41300	41400	41500	41600	41700	41800	41900
95	42000	42100	42200	42300	42400	42500	42600	42700	42800	42900
96	43000	43100	43200	43300	43400	43500	43600	43700	43800	43900
97	44000	44100	44200	44300	44400	44500	44600	44700	44800	44900
98	45000	45100	45200	45300	45400	45500	45600	45700	45800	45900
99	46000	46100	46200	46300	46400	46500	46600	46700	46800	46900
100	47000	47500	48000	48500	49000	49500	50000	50500	51000	51500
101	52000	52600	53200	53800	54400	55000	55600	56200	56800	57400
102	58000	58600	59200	59800	60400	61000	61600	62200	62800	63400
103	64000	64600	65200	65800	66400	67000	67600	68200	68800	69400
104	70000	70500	71000	71500	72000	72500	73000	73500	74000	74500
105	75000	75500	76000	76500	77000	77500	78000	78500	79000	79500
106	80000	80500	81000	81500	82000	82500	83000	83500	84000	84500
107	85000	85500	86000	86500	87000	87500	88000	88500	89000	89500
108	90000	90500	91000	91500	92000	92500	93000	93500	94000	94500
109	95000	95500	96000	96500	97000	97500	98000	98500	99000	99500
110	100000	100500	101000	101500	102000	102500	103000	103500	104000	104500

Table 3 The number of fall-run chinook salmon redds, riffle area, density of redds, and distance below Goodwin Dam for the 25 KFGRP riffles in the Stanislaus River in fall 1999. The project riffles were segregated into two areas. One area is where gravel was placed in fall 1999 as shown as the area within the polygons in the contour maps in Appendix 3; these areas are referred to as "inside" in the table's subheading below. The other area was immediately adjacent to where the gravel was added and is outside the polygons in the contour maps; these areas are referred to as "outside" in the table's subheading below. The areas used by spawners at the control sites are also referred to as "outside" in the table below.

Site	Number of Redds		Riffle Area (square-yards)		Redds/yd^2		Location
	Inside	Outside	Inside	Outside	Inside	Outside	Miles Below Goodwin Dam
TMA	125	29	256	118	0.488	0.246	1.70
TM1*	--	93	--	347		0.268	1.90
R1	128	29	282	70	0.453	0.414	3.95
R2**	--	95	--	352	--	0.270	4.00
R5	34	12	123	38	0.276	0.319	4.60
R10*	--	100	--	516	--	0.194	5.00
R11**	--	26	--	126	--	0.206	5.13
R12*	--	30	--	138	--	0.218	5.20
R12A	40	24	114	123	0.351	0.195	5.65
R12B	84	17	164	89	0.512	0.849	5.73
R13	101	--	341	--	0.296	--	5.77
R14	132	43	436	119	0.303	0.360	5.90
R14A	45	44	137	495	0.328	0.089	5.93
R15	45	6	175	26	0.257	0.227	5.99
R16	34	0	154	13	0.221	0.000	6.02
R19	88	77	316	419	0.278	0.184	6.37
R19A	79	--	193	--	0.409	--	6.44
R20*	--	192	--	1021	--	0.188	6.70
R26**	--	26	--	143	--	0.182	7.05
R27*	--	29	--	217	--	0.134	7.70
R28A	25	7	111	12	0.226	0.593	8.30
R29	29	13	107	96	0.271	0.135	8.75
R43	16	23	143	277	0.112	0.083	11.60
R44**	--	7	--	431	--	0.016	11.71
R57	30	--	191	--	0.157	--	13.90
R58	43	2	392	13	0.110	0.159	14.00
R59*	--	2	--	259	--	0.008	14.10
R76*	--	1	--	126	--	0.008	18.15
R78	3	0	291	190	0.010	0.000	18.30
Total	703	711	--	--	--	--	--
Average	--	--	218	214	0.281	0.221	--

* 1998 control sites
** new control sites

Table 4. The results of the *F*-test for each pair of regressions tested. The *F*-test requires that the variances of the regressions are not significantly different ($P > 0.05$) before the slopes are compared. If the slopes are not significantly different ($P > 0.05$), then the elevations can be compared. The probability of the final test for each set of comparisons are shown in bold font.

Comparison	*F*-statistic	*df*	*P*
Stanislaus River rock 1/4-inch screen vs Tuolumne River rock			
Equality of Variances	3.72	5, 4	0.114
Slopes	1.88	1, 9	0.204
Elevations	2.97	1, 10	**0.115**
Stanislaus River rock 3/8-inch screen vs Tuolumne River rock			
Equality of Variances	1.34	5, 4	0.401
Slopes	2.41	1, 9	0.155
Elevations	8.02	1, 10	**0.018**
Tuolumne River rock vs Control Sites			
Equality of Variances	2.41	4, 5	0.180
Slopes	0.37	1, 9	0.560
Elevations	10.43	1, 10	**0.009**
Stanislaus River rock 1/4-inch screen vs Stan 3/8-inch screen			
Equality of Variances	2.78	5, 5	0.143
Slopes	0.09	1, 10	0.770
Elevations	0.08	1, 11	**0.788**
Stanislaus River rock 1/4-inch screen vs Control Sites			
Equality of Variances	8.97	5, 5	**0.016**
Slopes	4.29	1, 10	0.065
Elevations	12.99	1, 11	0.004
Stanislaus River rock 3/8-inch screen vs Control Sites			
Equality of Variances	3.23	5, 5	0.112
Slopes	6.67	1, 10	0.027
Elevations	30.16	1, 11	**0.000**

Table 5. The volume of gravel placed in August and September 1999 and the volume mobilized between December 1999 and September 2000 in cubic yards, cubic yards of gravel per square yard of surface area where gravel was placed, and percent of total volume placed at the Knights Ferry Gravel Replenishment Project sites in the Stanislaus River. The riffles are grouped according to the pre-project streambed gradient upstream of the hydraulic control where a majority of the gravel was placed.

Riffle #	Rivermile	Gradient	Channel Width (ft)	Gravel Size	Placed cubic-yards	Mobilized cubic-yards	Mobilized volume/area	% Mobilized	Special Hydraulic Features
A) High-Crested Riffles (Tails of Deep Pools), 3.4% to 17.7% Streambed Gradient									
TMA	56.8	6.9%	121	1/4 to 5 inches	470	-33	-0.133	-7.1%	--
R1	54.55	10.5%	107	3/8 to 5 inches	395	-11	-0.040	-2.7%	--
R14A	52.57	5.4%	106	3/8 to 5 inches	1,055	-15	-0.075	-1.4%	--
R28A	50.2	5.2%	96	1/4 to 5 inches	250	-4	-0.031	-1.6%	--
R29	49.75	4.7%	104	3/8 to 5 inches	210	-30	-0.292	-14.4%	Steep Riffle Tail
B) Moderate-Crested Riffles, 1.6 to 3% Streambed Gradient									
R13	52.73	1.7%	113	3/8 to 5 inches	860	-79	-0.221	-9.2%	Boulders on Riffle Tail
R15	52.51	2.4%	170	3/8 to 5 inches	610	-2	-0.010	-0.2%	--
R16	52.48	2.8%	165	3/8 to 5 inches	240	-17	-0.091	-7.0%	--
R43	46.9	2.0%	92	3/8 to 5 inches	315	-48	-0.346	-15.1%	Upstream Bridge Pillar
R58	44.5	3.0%	102	1/4 to 5 inches	465	-32	-0.081	-6.9%	--
R78	40.2	2.5%	90	3/8 to 5 inches	405	-65	-0.235	-16.1%	UpstreamVegetated Bar
C) Low-Crested Riffles, 0 to 1.5% Streambed Gradient									
R5	53.9	-0.4%	81	3/8 to 5 inches	315	-61	-0.346	-19.5%	Large Horizontal Willow
R12A	52.82	0.9%	141	3/8 to 5 inches	380	-14	-0.112	-3.6%	--
R12B	52.77	1.5%	111	1/4 to 5 inches	470	-29	-0.163	-6.2%	--
R14	52.6	1.3%	109	1/4 to 5 inches	465	+20	+0.049	+4.4%	Wildcat Creek Confluence
R19	52.13	0.6%	121	1/4 to 5 inches	130	-26	-0.092	-19.7%	--
R19A	52.06	0.5%	109	3/8 to 5 inches	680	-34	-0.133	-5.0%	--
R57	44.6	0.1%	87	3/8 to 5 inches	645	-10	-0.054	-1.5%	--

Table 6. Streambed permeability (PERM) measured at a depth of 12 inches in undisturbed gravel approximately 18 inches from the piezometer (P) sites between 11 and 17 November 2000 and at chinook salmon redds during two surveys between November 2000 and January 2001 in 18 project riffles and 11 control riffles in the Stanislaus River between Goodwin Dam and Oakdale. The depth of the restoration gravel at the sampling location, the approximate age of the redd (± 5 days) when permeability was measured, and the estimated percent survival to emergence (% SURV) based on McCuddin's (1977) study are also presented.

		Undisturbed Gravel	Redds 11 - 17 Nov 2000			Redds 25 Dec 00 - 3 Jan 01		
Site	Gravel Type, Gravel Depth at Standpipe	PERM (cm/hr)	PERM (cm/hr)	AGE (days)	% SURV	PERM (cm/hr)	AGE (days)	% SURV
DFG2-P1	1997 Restoration	229,613				28,600	>60	77%
DFG2-P2	1997 Restoration	124,313				219,000	>60	77%
DFG2-P3	1997 Restoration	142,350				216,500	~42	77%
DFG2-P4	1997 Restoration					22,400	>60	77%
TMA-P1	Stanislaus 1/4" Screen, >18"	44,159				31,800	>59	77%
TMA-P2	Stanislaus 1/4" Screen, >18"	45,729				101,000	~53	77%
TMA-P3	Stanislaus 1/4" Screen, 6-12"	95,186				1,260	~42	24%
TMA-P4	Stanislaus 1/4" Screen, 6-12"	65,158				186,000	~32	77%
TM1-P1	Control Site-Natural	188	2,884	14-27	39%	1,780	>59	30%
TM1-P2	Control Site-Natural	1,225				28,100	>59	77%
TM1-P3	Control Site-Natural	8				7,850	~42	58%
TM1-P4	Control Site-Natural	109				88,500	>59	77%
R1-P1	Stanislaus 3/8" Screen, >18"	1,346	208,856	14-27	77%	40,682	>54*	77%
R1-P2	Stanislaus 3/8" Screen, >18"	607				24,946	~49	77%
R1-P3	Stanislaus 3/8" Screen, 6-12"	18,121				901	>54	17%
R1-P4	Stanislaus 3/8" Screen, 6-12"	632				4,908	>54	49%

Redds identified with an " * " for the December-January survey were the same redds measured in November

Table 6. Continued

Site	Gravel Type, Gravel Depth at Standpipe	Undisturbed Gravel PERM (cm/hr)	Redds 11 - 17 Nov 2000 PERM (cm/hr)	AGE (days)	% SURV	Redds 25 Dec 00 - 3 Jan 01 PERM (cm/hr)	AGE (days)	% SURV
R2	Control Site-Natural	--				3,736	?	44%
R2	Control Site-Natural	--				72	?	0%
R2	Control Site-Natural	--				884	?	17%
R2	Control Site-Natural	--				1,401	?	26%
R2	Control Site-Natural	--				4,829	?	49%
R5-P1	Tuolumne 3/8" Screen, > 18"	224,656				240,825	>55	77%
R5-P2	Tuolumne 3/8" Screen, > 18"	267,119				241,800	>55	77%
R5-P3	Tuolumne 3/8" Screen, > 18"	39,204				222,300	>55	77%
R5	Tuolumne 3/8" Screen, > 18"	--				247,650	>55	77%
R10-P1	Control Site-Natural	27,788	45,435	~6	77%	16,180	~49	71%
R10-P2	Control Site-Natural	6,572				40,300	~29	77%
R10-P3	Control Site-Natural	16,526				43,800	~49	77%
R10-P4	Control Site-Natural	14,703				13,940	~49	68%
R11	Control Site-Natural	--				2,597	?	37%
R11	Control Site-Natural	--				114,550	?	77%
R11	Control Site-Natural	--				593	?	10%
R11	Control Site-Natural	--				29,247	?	77%
R12-P1	Control Site-Natural	5,184	2,054	14-27	33%	245,000	>56	77%
R12-P2	Control Site-Natural	4,752	494	~6	6%	2,670	>56	38%
R12-P3	Control Site-Natural	1,613				1,510	~39	27%
R12-P4	Control Site-Natural	8,304				2,600	~29	37%

Redds identified with an “ * ” for the December-January survey were the same redds measured in November

Table 6. Continued

Site	Gravel Type, Gravel Depth at Standpipe	Undisturbed Gravel PERM (cm/hr)	Redds 11 - 17 Nov 2000 PERM (cm/hr)	AGE (days)	% SURV	Redds 25 Dec 00 - 3 Jan 01 PERM (cm/hr)	AGE (days)	% SURV
R12A-P1	Stanislaus 3/8" Screen, > 18"	25,962	8,698	14-28	60%	186,714	~55	77%
R12A-P2	Stanislaus 3/8" Screen, > 18"	199,923				187,726	>61	77%
R12A-P3	Stanislaus 3/8" Screen, > 18"	2,558				136,620	~45	77%
R12A-P4	Stanislaus 3/8" Screen, > 18"	109,436				127,006	~45	77%
R12B-P1	Stanislaus 1/4" Screen, > 18"	24,534	4,042	14-28	45%	27,100	>61	77%
R12B-P2	Stanislaus 1/4" Screen, > 18"	133,950				2,970	~55	40%
R12B-P3	Stanislaus 1/4" Screen, > 18"	133,950				3,740	~55	44%
R12B-P4	Stanislaus 1/4" Screen, > 18"	3,704				92,500	~35	77%
R13-P1	Stanislaus 3/8" Screen, > 18"	5,132	235,940	~6	77%	164,457	>61	77%
R13-P2	Stanislaus 3/8" Screen, > 18"	3,986				108,313	>61	77%
R13-P3	Stanislaus 3/8" Screen, > 18"	4,907				10,414	~44	63%
R13-P4	Stanislaus 3/8" Screen, > 18"	4,061				64,789	>61	77%
R14-P1	Stanislaus 1/4" Screen, ~12"	69,480	5,732	~7	52%	13,580	~44	68%
R14-P2	Stanislaus 1/4" Screen, 6-12"	2,528	176,113	~7	77%	17,510	~44	73%
R14-P3	Stanislaus 1/4" Screen, 6-12"	14,436				1,190	>62	23%
R14-P4	Stanislaus 1/4" Screen, 6-12"	434				62,580	~52	77%
R14A-P1	Stanislaus 3/8" Screen, > 18"	86,905	154,710	~14	77%	3,503	>62	43%
R14A-P2	Stanislaus 3/8" Screen, > 18"	117,465				48,688	~45	77%
R14A-P3	Stanislaus 3/8" Screen, > 18"	11,632				278,288	~53	77%
R14A-P4	Stanislaus 3/8" Screen, > 18"	3,381				83,025	~45	77%
R15-P1	Tuolumne 3/8" Screen, > 18"	1,649	12,033	~6	66%	784	~45	15%
R15-P2	Tuolumne 3/8" Screen, > 18"	839				20,541	~45	76%
R15-P3	Tuolumne 3/8" Screen, > 18"	1,122				179,375	>61	77%
R15-P4	Tuolumne 3/8" Screen, > 18"	3,619				13,838	~45	68%

Redds identified with an " * " for the December-January survey were the same redds measured in November

Table 6. Continued

Site	Gravel Type, Gravel Depth at Standpipe	Undisturbed Gravel	Redds 11 - 17 Nov 2000			Redds 25 Dec 00 - 3 Jan 01		
		PERM (cm/hr)	PERM (cm/hr)	AGE (days)	% SURV	PERM (cm/hr)	AGE (days)	% SURV
R16-P1	Tuolumne 3/8" Screen, ~12"	69	1,251	~6	24%	835	~53	16%
R16-P2	Tuolumne 3/8" Screen, ~12"	1,327	210,578	~6	77%	1,200	~53	23%
R16-P3	Tuolumne 3/8" Screen, 6-12"	4,651				505	~45	7%
R16-P4	Tuolumne 3/8" Screen, 6-12"	1,652				740	>61	14%
R19-P1	Stanislaus 1/4" Screen, ~12"	32,714	10,036	~7	62%	28,300	~53*	77%
R19-P2	Stanislaus 1/4" Screen, ~12"	565				11,480	~46	65%
R19-P3	Stanislaus 1/4" Screen, ~12"	2,335				11,820	>62	65%
R19-P4	Stanislaus 1/4" Screen, ~12"	685				1,500	~46	27%
R19	Natural Gravel	---	3,551	~7	43%	665	~53	12%
R19	Natural Gravel	--	31,845	~7	77%	44,800	>62	77%
R19	Natural Gravel	--				15,620	~53	71%
R19A-P1	Stanislaus 3/8" Screen, > 18"	18,518	184,315	~7	77%	1,847	~53*	31%
R19A-P2	Stanislaus 3/8" Screen, > 18"	62				11,712	~46	65%
R19A-P3	Stanislaus 3/8" Screen, > 18"	2,355				254,775	~46	77%
R19A-P4	Stanislaus 3/8" Screen, > 18"	4,343				38,710	>62	77%
R19A	Stanislaus 3/8" Screen, > 18"	--				253,294	~53	77%
R20-P1	Control Site-Natural	5,451	5,277	~7	50%	56,442	~52	77%
R20-P2	Control Site-Natural	2,706	12,028	~7	66%	261,840	>61	77%
R20-P3	Control Site-Natural	587				80,987	>61	77%
R20-P4	Control Site-Natural	54				3,200	~52	41%

Redds identified with an “ * ” for the December-January survey were the same redds measured in November

Table 6. Continued

Site	Gravel Type, Gravel Depth at Standpipe	Undisturbed Gravel	Redds 11 - 17 Nov 2000			Redds 25 Dec 00 - 3 Jan 01		
		PERM (cm/hr)	PERM (cm/hr)	AGE (days)	% SURV	PERM (cm/hr)	AGE (days)	% SURV
R26	Control Site-Natural	11,060				2,880	?	39%
R26	Control Site-Natural	4,720				124,000	?	77%
R26	Control Site-Natural	3,280				1,440	?	26%
R26	Control Site-Natural	1,990				4,100	?	46%
R27-P1	1994 Restoration	25	21,010	~7	76%	2,287	~53*	35%
R27-P2	1994 Restoration	3,782				5,320	>62	51%
R27-P3	1994 Restoration	1,700				1,439	~53	26%
R27-P4	1994 Restoration	12,320				5,837	~36	52%
R28A-P1	Stanislaus 1/4" Screen, > 18"	3,627	26,033	~7	77%	3,772	~52	44%
R28A-P2	Stanislaus 1/4" Screen, > 18"	6,835				246	~36	0%
R28A-P3	Stanislaus 1/4" Screen, > 18"	25,838				9,533	~52	61%
R28A-P4	Stanislaus 1/4" Screen, > 18"	4,056				7,339	~36	57%
R29-P1	Tuolumne 3/8" Screen, ~12"	120,900	19,383	~7	75%	168,613	~53	77%
R29-P2	Tuolumne 3/8" Screen, ~12"	1,482				3,260	~45	41%
R29-P3	Tuolumne 3/8" Screen, 6-12"	1,726				415	>61	3%
R29-P4	Tuolumne 3/8" Screen, 6-12"	1,677				150,675	~53	77%
R43-P1	Tuolumne 3/8" Screen, > 18"	11,870	128,828	~7	77%	44,933	~45	77%
R43-P2	Tuolumne 3/8" Screen, > 18"	5,018				12,893	~52	67%
R43	Tuolumne 3/8" Screen, > 18"	--				141,174	>61	77%
R43	Tuolumne 3/8" Screen, > 18"	--				120,428	~52	77%
R43-P3	Natural	695	2,865	~7	39%	506	~35	7%
R43-P4	Natural	473						

Redds identified with an “ * ” for the December-January survey were the same redds measured in November

Table 6. Continued

Site	Gravel Type, Gravel Depth at Standpipe	Undisturbed Gravel PERM (cm/hr)	Redds 11 - 17 Nov 2000 PERM (cm/hr)	AGE (days)	% SURV	Redds 25 Dec 00 - 3 Jan 01 PERM (cm/hr)	AGE (days)	% SURV
R44	Control Site-Natural	1,400				26,500	?	77%
R44	Control Site-Natural	2,550				980	?	19%
R44	Control Site-Natural	835				1,890	?	31%
R44	Control Site-Natural	230				1,180	?	22%
R57-P1	Stanislaus 3/8" Screen, > 18"	2,384	4,323	~7	47%	32,810	~48	77%
R57-P2	Stanislaus 3/8" Screen, > 18"	16,357	145,233	~7	77%	208,035	~48	77%
R57-P3	Stanislaus 3/8" Screen, > 18"	1,660				89,010	~55	77%
R57-P4	Stanislaus 3/8" Screen, > 18"	128,828				8,839	~55	60%
R58-P1	Stanislaus 1/4" Screen, ~12"	169,200	29,328	~5	77%	144,200	~59*	77%
R58-P2	Stanislaus 1/4" Screen, ~12"	9,513				42,951	~48	77%
R58-P3	Stanislaus 1/4" Screen, 6-12"	113				2,936	>64	39%
R58-P4	Stanislaus 1/4" Screen, 6-12"	64				1,545	~48	27%
R58	Stanislaus 1/4" Screen, 6-12"	--	1,231	14-29	23%	15,409	>64	70%
R59-P1	Control Site-Natural	461	8,667	~5	60%	3,003	~59*	40%
R59-P2	Control Site-Natural	150				74	~59	0%
R59-P3	Control Site-Natural	56						
R59-P4	Control Site-Natural	338						
R76-P1	Control Site-Natural	4,757						
R76-P2	Control Site-Natural	270						
R76-P3	Control Site-Natural	42,750						
R76-P4	Control Site-Natural	309						
R78-P1	Tuolumne 3/8" Screen, 6-12"	735				135,445	~60	77%
R78-P2	Tuolumne 3/8" Screen, ~12"	350				140,595	~53	77%
R78-P3	Tuolumne 3/8" Screen, 6-12"	656						
R78-P4	Tuolumne 3/8" Screen, ~12"	1,594						

Redds identified with an “ * ” for the December-January survey were the same redds measured in November

Table 7. Side-by-side measurements of apparent velocity and permeability at an initial depth of 12 inches in artificial redds in 16 project riffles and 6 control riffles in the Stanislaus River between Goodwin Dam and Oakdale during four surveys that began on 15 October, 4 November, 25 December 2000, and 5 February 2001. The apparent velocity sensor number indicates the direction of flow for the November (N), December (D), and February (F) surveys. Sensor numbers 1, 2 and 8 indicate downstream flow, sensor numbers 3 and 7 indicate sideways flow, and sensor numbers 4, 5, and 6 indicate upstream flow. The amount of gravel deposited or scoured from redd superimposition and the estimated percent survival to emergence (% SURV) based permeability measurements from McCuddin's (1977) study are also presented.

	Apparent Velocity (ft/hr)				Sensor			Permeability (cm/hr)		Nearby Redd Construction	
Site	15 Oct	4 Nov	25 Dec	5 Feb	N	D	F	5 Feb	% Surv	Nov Survey	Dec & Feb Surveys
R1-P1	--	0.4	0.8	0.5	1	1	1	13,575	68	No Change	2" Scour
R1-P2	--	8.2	1.9	1.8	1	1	1	234,840	77	7" Scour	2" Deposit
R1-P3	--	3.5	4.7	4.4	1	1	1	111,240	77	6" Scour	6" Scour
R1-P4	--	1.2	1.2	0.3	7	6	1	14,221	69	6" Deposit	3" Scour
R5-P1	--	4.4	3.3	1.3	1	1	1	311,190	77	No Change	3" Scour
R5-P2	--	4.0	--	--	1	-	-	--	--	No Change	Destroyed
R10-P1	--	3.8	--	--	1	-	-	--	--	8" Scour	Destroyed
R10-P2	--	--	--	--	-	-	-	--	--	Destroyed	Destroyed
R10-P3	--	1.3	0.3	0.4	8	1	1	4,930	49	5" Scour	5" Scour
R10-P4	--	0.8	2.0	0.4	2	1	1	31,900	77	6" Scour	6" Scour
R12-P2	--	0.8	1.3	1.1	1	1	1	1,876	31	6" Scour	6" Scour
R12A P1	1.8	0.2	--	--	4	-	-	--	--	No Change	Well Filled
R12A P2	1.5	0.8	0.4	0.7	1	1	1	49,163	77	5" Scour	5" Scour
R12A P3	--	1.6	4.7	1.8	4	1	2	1,875	31	8" Scour	8" Scour
R12A P4	3.3	1.6	2.4	2.8	1	3	3	47,150	77	8" Scour	8" Scour
R12B P1	1.3	0.9	--	--	2	-	-	--	--	6" Scour	Destroyed
R12B P2	1.1	0.6	0.5	0.3	4	1	5	7,093	56	4" Scour	Disturbed
R12B P3	1.7	0.9	3.0	1.4	1	1	1	3,663	44	No Change	Disturbed
R12B P4	17.8	2.4	7.0	0.1	4	1	2	9,452	61	No Change	2" Deposit
R13 P1	5.6	4.8	3.4	2.8	1	1	1	2,277	35	No Change	1" Deposit
R13 P2	4.3	6.6	--	--	1	-	-	--	--	8" Scour	Destroyed
R13 P3	1.5	--	0.5	0.4	-	6	4	582	9	Disturbed	4" Deposit
R13 P4	6.8	--	2.2	0.5	-	6	4	2,176	34	4" Deposit	Disturbed
R14 P1	--	0.3	1.4	0.2	2	2	1	9,367	61	No Change	2" Deposit
R14 P2	--	--	0.7	0.5	-	4	2	1,780	30	7" Deposit	7" Deposit
R14 P3	--	0.4	1.2	1.0	4	4	2	14,221	69	No Change	10" Deposit
R14 P4	--	0.3	--	--	1	-	-	--	--	No Change	Destroyed
R14A P1	--	6.4	9.4	10.4	1	1	1	3,053	40	9" Scour	9" Scour
R14A P2	--	0.8	2.1	7.9	1	2	1	84,050	77	No Change	8" Scour
R14A P3	--	--	--	--	-	-	-	--	--	Destroyed	Destroyed
R14A P4	--	--	--	--	-	-	-	--	--	Destroyed	Destroyed

Table 7. Continued

Site	Apparent Velocity (ft/hr) 15 Oct	4 Nov	25 Dec	5 Feb	Sensor N	D	F	Permeability (cm/hr) 5 Feb	% Surv	Nearby Redd Construction Nov Survey	Dec & Feb Surveys
R15 P1	--	0.3	3.0	1.5	1	1	1	195,185	77	No Change	7" Scour
R15 P2	--	0.3	0.9	0.7	4	1	4	2,542	37	No Change	No Change
R15 P3	--	4.2	1.8	0.2	1	1	1	215	0	No Change	2" Scour
R15 P4	--	2.2	1.5	0.1	4	4	1	3,711	44	No Change	No Change
R16 P1	--	2.6	5.5	2.3	1	1	2	707	13	6" Scour	6" Scour
R16 P2	--	1.2	1.7	1.1	2	2	2	267	0	No Change	2" Deposit
R16 P3	--	5.7	1.3	0.7	2	4	2	564	9	4" Scour	2" Deposit
R16 P4	--	--	4.6	2.4	-	1	1	14,781	70	No Change	2" Deposit
R19 P1	3.5	--	--	--	-	-	-	--		Well Filled	Well Filled
R19 P2	9.8	4.6	3.0	1.9	1	1	1	199,413	77	No Change	No Change
R19 P3	3.7	0.4	--	--	4	-	-	--	--	No Change	Destroyed
R19 P4	6.1	1.2	--	--	1	-	-	--	--	No Change	Destroyed
R19A P1	7.9	1.8	0.4	0.4	1	1	4	7,194	56	No Change	No Change
R19A P2	5.6	1.1	1.1	0.2	1	2	1	3,047	40	3" Scour	3" Scour
R19A P3	6.6	4.0	0.9	0.1	1	4	1	323	0	No Change	2" Deposit
R19A P4	17.7	2.3	4.7	2.1	1	1	1	3,036	40	No Change	No Change
R20 P1	--	2.8	1.6	1.3	1	1	1	2,577	37	8" Scour	8" Scour
R20 P2	--	1.0	3.9	1.9	1	1	2	2,846	39	No Change	6" Scour
R20 P3	--	0.1	--	--	4	-	-	--	--	No Change	Destroyed
R20 P4	--	0.6	--	--	2	-	-	40,469	77	6" Deposit	Disturbed
R27 P1	--	6.3	2.7	2.6	1	1	1	40	0	2" Scour	No Change
R27 P2	--	2.4	26.6	4.9	1	1	1	920	18	4" Deposit	3" Scour
R27 P3	--	4.1	1.0	1.1	1	1	1	1,144	22	No Change	No Change
R27 P4	--	5.9	0.7	0.7	2	2	1	2,490	36	No Change	No Change
R28A P1	--	1.9	5.3	1.4	1	1	1	127,100	77	No Change	No Change
R28A P2	--	3.9	8.5	6.1	1	1	1	41,923	77	2" Deposit	2" Deposit
R29 P1	--	3.6	1.9	1.4	1	1	1	10,980	64	No Change	4" Scour
R29 P2	--	3.0	4.1	1.2	1	1	1	29,100	77	No Change	2" Deposit
R29 P3	--	3.4	2.5	1.6	4	4	4	183,000	77	6" Deposit	6" Deposit
R29 P4	--	3.0	4.0	4.1	2	1	3	1,860	31	No Change	No Change
R57 P1	--	1.1	1.1	0.1	1	6	5	190	0	No Change	2" Deposit
R57 P2	--	1.0	2.0	0.7	8	1	2	78,821	77	No Change	No Change
R57 P3	--	1.4	5.4	1.0	6	8	2	85	0	No Change	No Change
R57 P4	--	1.1	0.9	0.4	6	1	1	7,766	58	No Change	No Change

Table 7. Continued

Site	Apparent Velocity (ft/hr) 15 Oct	4 Nov	25 Dec	5 Feb	Sensor N	D	F	Permeability (cm/hr) 5 Feb	% Surv	Nearby Redd Construction Nov Survey	Dec & Feb Surveys
R58 P1	--	7.7	4.7	3.7	1	2	1	75,555	77	No Change	No Change
R58 P2	--	2.1	2.5	1.9	1	1	2	343,850	77	3" Deposit	2" Deposit
R58 P3	--	3.9	1.1	0.4	8	8	5	122,570	77	No Change	Disturbed
R58 P4	--	4.1	0.9	0.6	1	2	8	725	13	No Change	1" Deposit
R59 P1	--	--	2.4	0.9	-	2	1	12,502	66	2" Deposit	2" Deposit
R59 P2	--	1.1	0.1	0.5	2	1	7	5,638	52	No Change	No Change
R59 P3	--	0.3	0.3	0.2	1	1	1	1,639	29	No Change	No Change
R59 P4	--	0.5	0.6	0.1	1	2	3	2,580	37	No Change	2" Deposit
R76 P1	--	2.7	2.0	0.1	8	8	1	545	8	No Change	No Change
R76 P2	--	1.7	0.7	0.7	1	1	1	349	0	No Change	No Change
R76 P3	--	3.7	11.6	1.1	1	1	1	492	6	No Change	No Change
R76 P4	--	1.3	0.6	1.1	1	1	5	1,625	28	No Change	No Change
R78 P1	--	4.6	5.8	0.2	8	1	4	9,315	61	No Change	No Change
R78 P2	--	1.5	3.8	0.2	8	1	4	269,860	77	No Change	No Change
R78 P3	--	1.8	0.9	0.5	1	8	6	4,388	47	No Change	No Change
R78 P4	--	1.6	2.4	0.3	3	1	6	28,187	77	No Change	No Change

Table 8. Intragravel and surface dissolved oxygen concentrations in parts-per-million at piezometers (P) buried in artificial redds at 16 project riffles and six control riffles in the Stanislaus River between Goodwin Dam and Oakdale during seven surveys between 15 October 2000 and February 2001. Measurements during the 6-9 February 2001 survey were made following turbid storm runoff.

Site	15-16 Oct	3-13 Nov	22-24 Nov	2-4 Dec	15-18 Dec	25 Dec - 6 Jan	5-15 Feb
R1-P1	--	9.7	10.6	10.4	10.2	--	9.4
R1-P2	--	9.9	11.1	10.1	10.5	10.2	10.8
R1-P3	--	10.1	10.9	10.8	11.2	10.5	11.0
R1-P4	--	9.9	10.4	10.4	10.5	9.6	10.9
R1- Surface	--	10.4	11.8	11.4	11.4	11.9	11.4
R5-P1	--	10.4	11.2	11.9	11.6	11.8	11.5
R5-P2	--	10.4	10.8	11.8	11.6	--	--
R5-Surface	--	10.5	11.8	11.9	11.7	12.1	11.2
R10-P1	--	9.3	10.6	9.6	9.6	9.2	--
R10-P2	--	--	--	--	--	--	--
R10-P3	--	8.8	10.0	10.1	10.8	10.1	10.2
R10-P4	--	10.3	10.0	10.2	10.8	11.1	10.3
R10- Surface	--	10.7	11.8	11.4	11.7	10.8	11.7
R12-P1	--	--	--	--	--	--	--
R12-P2	--	10.1	10.6	11.6	11.1	11.2	10.4
R12-Surface	--	10.7	11.9	12.1	11.7	12.1	11.1
R12A-P1	11.6	10.1	10.6	--	11.2	11.6	--
R12A-P2	11.5	10.2	9.0	8.8	9.1	9.7	9.7
R12A-P3	11.2	10.8	11.0	10.4	8.5	8.7	9.2
R12A-P4	11.3	10.8	10.9	--	10.4	9.4	9.7
R12A-Surface	12.2	11.6	11.8	11.9	11.6	12.4	11.2
R12B-P1	10.6	10.0	--	--	--	--	--
R12B-P2	10.6	10.0	9.7	10.6	9.4	9.6	8.9
R12B-P3	11.0	10.7	--	--	--	--	--
R12B-P4	11.2	10.6	11.3	11.1	10.8	10.5	11.1
R12B-Surface	11.5	10.9	11.9	11.9	11.6	12.1	11.8
R13-P1	10.7	10.3	9.4	10.8	10.9	10.8	10.3
R13-P2	11.0	--	--	--	--	--	--
R13-P3	--	--	--	9.8	--	--	--
R13-P4	11.4	--	8.8	10.2	10.1	10.4	9.7
R13-Surface	11.5	11.2	10.7	12.1	11.7	12.6	11.8
R14-P1	--	10.0	10.2	9.4	9.5	11.1	9.7
R14-P2	--	--	--	10.0	10.1	11.4	9.6
R14-P3	--	10.2	9.8	10.4	9.7	11.2	9.9
R14-P4	--	9.1	8.4	8.2	8.7	8.9	--
R14-Surface	--	11.0	10.9	11.1	10.7	12.5	11.0

Table 8. Intragravel and surface dissolved oxygen concentrations in ppm (Continued)

Site	15-16 Oct	3-13 Nov	22-24 Nov	2-4 Dec	15-18 Dec	25 Dec - 6 Jan	5-15 Feb
R14A-P1	--	10.2	10.6	10.8	10.6	10.2	11.3
R14A-P2	--	10.6	10.2	10.7	10.4	10.5	11.3
R14A-P3	--	--	--	--	--	--	--
R14A-P4	--	--	--	--	--	--	--
R14A-Surface	--	11.0	11.2	11.2	11.0	11.1	11.3
R15-P1	--	11.2	10.9	10.4	10.1	11.1	11.4
R15-P2	--	10.6	6.5	10.2	10.1	10.0	10.3
R15-P3	--	11.1	10.1	10.9	9.5	11.6	10.7
R15-P4	--	8.8	7.3	9.4	8.7	10.4	9.8
R15-Surface	--	12.0	11.2	11.3	10.9	12.2	11.8
R16-P1	--	9.0	9.1	6.7	6.4	7.5	7.6
R16-P2	--	9.4	9.7	10.1	10.2	11.2	10.6
R16-P3	--	--	--	10.5	10.1	--	--
R16-P4	--	9.8	10.6	10.5	10.2	10.7	11.1
R16-Surface	--	10.0	11.4	11.2	10.9	11.6	11.8
R19-P1	11.0	9.9	--	--	--	--	--
R19-P2	10.7	9.5	10.0	10.1	8.5	8.9	8.2
R19-P3	10.8	9.8	10.4	10.3	9.9	11.0	--
R19-P4	10.7	7.8	--	--	--	--	--
R19-Surface	11.6	10.3	11.5	11.5	11.2	12.2	11.2
R19A-P1	11.2	9.7	10.8	10.6	10.7	11.1	10.5
R19A-P2	10.6	9.3	9.9	10.2	9.9	11.0	10.7
R19A-P3	11.2	9.9	10.6	11.1	10.4	11.1	11.2
R19A-P4	10.9	9.2	9.5	10.3	9.7	9.0	10.5
R19A-Surface	11.5	10.4	11.7	12.1	11.5	12.6	11.4
R20-P1	--	9.6	10.7	11.3	10.5	10.9	11.3
R20-P2	--	9.9	10.0	10.8	10.1	11.0	10.8
R20-P3	--	9.5	--	--	--	--	--
R20-P4	--	9.2	10.7	10.7	10.7	10.9	11.2
R20-Surface	--	10.5	11.8	12.0	11.4	12.4	11.8
R27-P1	--	10.2	10.9	11.6	11.0	11.1	11.4
R27-P2	--	9.4	11.0	11.6	10.8	10.8	11.2
R27-P3	--	9.2	9.8	10.3	9.6	10.3	11.0
R27-P4	--	9.2	10.2	10.6	9.8	10.3	10.5
R27-Surface	--	10.4	11.6	12.1	11.3	11.5	11.7
R28A-P1		10.0	10.4	10.7	10.8	11.0	11.5
R28A-P2		9.2	10.6	10.5	10.4	10.1	11.3
R28A-Surface		10.4	11.5	11.3	11.5	11.2	12.0

Table 8. Intragravel and surface dissolved oxygen concentrations in ppm (Continued)

Site	15-16 Oct	3-13 Nov	22-24 Nov	2-4 Dec	15-18 Dec	25 Dec - 6 Jan	5-15 Feb
R29-P1	--	11.4	10.3	10.0	10.7	11.4	11.6
R29-P2	--	11.6	10.7	9.9	10.8	11.1	10.9
R29-P3	--	11.2	--	10.0	10.8	11.0	11.0
R29-P4	--	9.0	9.9	9.5	9.5	10.6	10.1
R29-Surface	--	11.7	11.4	10.2	12.0	11.8	12.0
R57-P1	--	10.4	9.5	8.8	8.8	8.6	9.3
R57-P2	--	10.7	10.1	9.9	10.0	10.3	10.7
R57-P3	--	9.4	8.6	8.1	8.4	10.4	9.4
R57-P4	--	10.4	10.0	9.2	9.7	10.8	11.1
R57-Surface	--	11.5	11.2	10.7	11.2	11.8	11.3
R58-P1	--	10.3	9.4	9.6	10.0	10.4	10.4
R58-P2	--	9.8	9.1	9.4	10.0	10.6	10.1
R58-P3	--	10.2	10.1	9.6	9.8	10.4	10.2
R58-P4	--	9.4	10.1	9.1	10.0	10.6	10.3
R58-Surface	--	11.4	11.1	10.7	11.1	12.1	11.6
R59-P1	--	10.3	9.2	9.2	9.3	9.8	10.3
R59-P2	--	9.6	9.2	8.6	8.0	--	8.0
R59-P3	--	7.2	7.6	7.3	7.5	8.0	8.3
R59-P4	--	8.1	8.6	8.9	8.0	8.6	7.5
R59-Surface	--	11.6	11.0	11.1	11.4	12.4	11.8
R76-P1	--	9.7	9.5	10.0	10.4	11.2	10.1
R76-P2	--	9.1	9.5	9.2	9.5	11.2	9.8
R76-P3	--	9.3	8.0	8.8	9.3	11.2	9.7
R76-P4	--	10.0	9.4	9.6	9.6	11.2	9.3
R76-Surface	--	10.6	10.6	10.9	11.6	11.8	10.6
R78-P1	--	10.4	10.0	10.9	10.1	11.9	11.0
R78-P2	--	8.8	7.9	8.9	9.2	10.9	8.8
R78-P3	--	10.6	10.1	10.6	10.4	11.3	9.3
R78-P4	--	10.4	9.3	9.9	10.0	11.7	10.5
R78-Surface	--	11.3	10.6	11.3	11.6	12.2	11.7

Table 9. Vertical hydraulic gradient (VHG) at piezometers (P) at 16 project riffles and six control riffles in the Stanislaus River between Goodwin Dam and Oakdale during three surveys between November 2000 and February 2001. Measurements during the February 2001 survey were made several days after storm runoff.

Piezometer	3-13 Nov	25 Dec - 6 Jan	5-15 Feb
R1-P1	0.033	0.000	0.007
R1-P2	0.049	0.016	0.016
R1-P3	0.033	0.007	0.016
R1-P4	0.000	0.016	0.025
R5-P1	0.007	0.033	0.039
R5-P2	0.066	–	–
R10-P1	0.000	0.000	–
R10-P2	–	–	–
R10-P3	0.016	-0.016	-0.025
R10-P4	0.049	-0.008	0.000
R12-P1	–	–	–
R12-P2	0.016	0.016	0.007
R12A-P1	0.016	0.000	–
R12A-P2	0.033	0.000	–
R12A-P3	0.000	-0.008	0.000
R12A-P4	0.016	0.000	–
R12B-P1	0.016	–	–
R12B-P2	0.016	-0.008	0.000
R12B-P3	-0.007	–	–
R12B-P4	0.007	0.008	0.016
R13-P1	-0.049	-0.066	-0.082
R13-P2	–	–	–
R13-P3	–	–	–
R13-P4	–	0.049	-0.008
R14-P1	-0.013	0.016	0.007
R14-P2	–	0.008	0.000
R14-P3	0.033	0.041	-0.025
R14-P4	0.016	-0.016	–
R14A-P1	0.016	0.016	0.007
R14A-P2	0.025	0.000	–
R14A-P3	–	–	–
R14A-P4	–	–	–
R15-P1	0.000	0.008	0.000
R15-P2	0.000	0.008	-0.008
R15-P3	0.016	0.016	-0.007
R15-P4	0.003	-0.025	-0.049
R16-P1	0.016	0.098	0.008
R16-P2	0.049	0.016	0.000
R16-P3	–	–	–
R16-P4	-0.049	-0.066	0.049

Table 9. Continued.

Piezometer	3-13 Nov	25 Dec - 6 Jan	5-15 Feb
R19-P1	0.049	–	–
R19-P2	0.066	-0.008	-0.003
R19-P3	0.033	-0.033	–
R19-P4	0.033	–	–
R19A-P1	0.049	-0.049	0.000
R19A-P2	0.033	0.033	-0.025
R19A-P3	-0.016	-0.007	0.025
R19A-P4	-0.016	0.007	0.003
R20-P1	0.000	-0.115	-0.131
R20-P2	0.000	-0.033	0.000
R20-P3	0.016	–	–
R20-P4	-0.016	-0.066	-0.082
R27-P1	0.033	0.008	0.033
R27-P2	0.033	0.000	0.016
R27-P3	-0.016	0.000	-0.025
R27-P4	0.049	-0.008	-0.026
R28A-P1	0.016	-0.041	0.003
R28A-P2	0.033	0.008	-0.003
R29-P1	0.033	0.000	0.007
R29-P2	0.000	0.000	0.049
R29-P3	0.000	0.000	–
R29-P4	0.000	-0.008	0.000
R57-P1	0.016	0.000	0.049
R57-P2	0.033	0.008	0.075
R57-P3	-0.016	0.000	0.008
R57-P4	0.033	0.000	-0.025
R58-P1	0.016	0.033	0.033
R58-P2	0.033	0.041	0.039
R58-P3	0.033	-0.041	0.025
R58-P4	0.033	-0.025	-0.016
R59-P1	–	0.049	0.049
R59-P2	0.000	0.057	-0.010
R59-P3	0.016	0.000	-0.023
R59-P4	-0.049	0.008	-0.010
R76-P1	-0.049	-0.016	-0.041
R76-P2	0.000	-0.016	0.007
R76-P3	-0.016	0.000	-0.057
R76-P4	0.082	0.016	-0.003
R78-P1	0.033	-0.033	0.041
R78-P2	-0.033	-0.033	0.007
R78-P3	0.016	0.000	-0.033
R78-P4	0.033	0.033	–

Table 10. The deviation in intragravel water temperature from surface water temperature, the mean intragravel dissolved oxygen (D.O.) concentration in percent saturation and apparent velocity (AV) in December 2000 and February 2001, and the bed permeability at the artificial redds during February 2001 for the piezometers where elevated intragravel water temperatures were observed and the mean for sites where no temperature deviations occurred. Stable deviations occurred when the range in daily fluctuation in the intragravel water temperature was less than 75% of the range in the surface water temperature.

Piezometer	Temp Deviation (F)	AV (ft/hr)	D.O. (% Sat)	PERM (cm/hr)
R1 P1-Project	Stable after 12/22	0.50	*82.5%	13,575
R10 P1-Natural	Stable after Oct pulse flow	--	83.1%	--
R14 P1-Project	Stable from beginning	0.77	87.2%	9,367
R20 P2-Natural	Stable from beginning	2.90	90.0%	2,846
R29 P4-Project	Stable from beginning	4.08	85.5%	1,860
R57 P1-Project	Elevated by 0.5 F after 10/14	0.60	81.0%	190
R58 P3-Project	Elevated by 1.9 F after 11/24	0.74	88.6%	122,570
R59 P1-Natural	Elevated by 1.2 F after Oct pulse flow	1.62	83.9%	12,502
R59 P2-Natural	Elevated by 1.8 F after Oct pulse flow	0.30	71.8%	5,638
R59 P3-Natural	Elevated by 5.4 F from beginning	0.25	67.3%	1,639
R59 P4-Natural	Elevated by 3.9 F after Oct pulse flow	0.37	71.3%	2,580
R76 P4-Project	Stable after Oct pulse flow	0.88	86.2%	1,625
R78 P2-Project	Elevated by 0.4 F after Oct pulse flow	2.01	77.8%	269,860
R78 P3-Project	Stable after 12/30	0.50	*79.5%	4,388
R78 P4-Project	Stable after 11/15	1.38	87.9%	28,187
Mean Other Sites	No Deviations	2.45	89.7%	47,891

* Dissolved oxygen and apparent velocity were measured during the February survey; otherwise reported value is mean for December and February surveys.

Table 11. The approximate number of entombed alevins and eggs observed when retrieving piezometers from artificial redds that were superimposed by at least two chinook salmon redds in February 2001.

Artificial Redd	Number of Superimposing Redds	Alevin or Egg Mortalities
R10 P2	Two during surveys 1 and 2	No mortalities
R12A P1	Three during surveys 1, 3, and 4	No mortalities
R12B P2	Two during surveys 2 and 3	~50 dead alevins
R12B P3	Two during surveys 2 and 3	No mortalities
R13 P1	Two during surveys 1 and 4	~10 dead alevins
R13 P3	Two during surveys 1 and 3	~25 dead alevins
R13 P4	Two during surveys 1 and 2	No mortalities
R14 P1	Three during surveys 1, 2, and 3	No mortalities
R14 P2	Three during surveys 1, 2, and 3	No mortalities
R14 P3	Three during surveys 1, 3, and 6	~25 dead alevins
R14 P4	Two during surveys 1 and 2	~25 dead alevins
R16 P4	Two during surveys 1 and 4	No mortalities
R19 P2	Four during surveys 1, 2, 3, and 6	No mortalities
R19 P3	Two during surveys 2 and 6	No mortalities
R20 P3	Two during surveys 4 and 6	~100 dead alevins, ~100 trapped alevins, and many dead eggs.
R20 P4	Three during surveys 1, 3, and 6	No mortalities
R29 P2	Two during surveys 1 and 2	No mortalities
R57 P1	Two during surveys 2 and 5	No mortalities
R58 P3	Two during surveys 3 and 5	No mortalities

APPENDIX 3

Fall 1999 and Fall 2000 Post-Project Contour Maps of Study Sites and Redd Locations

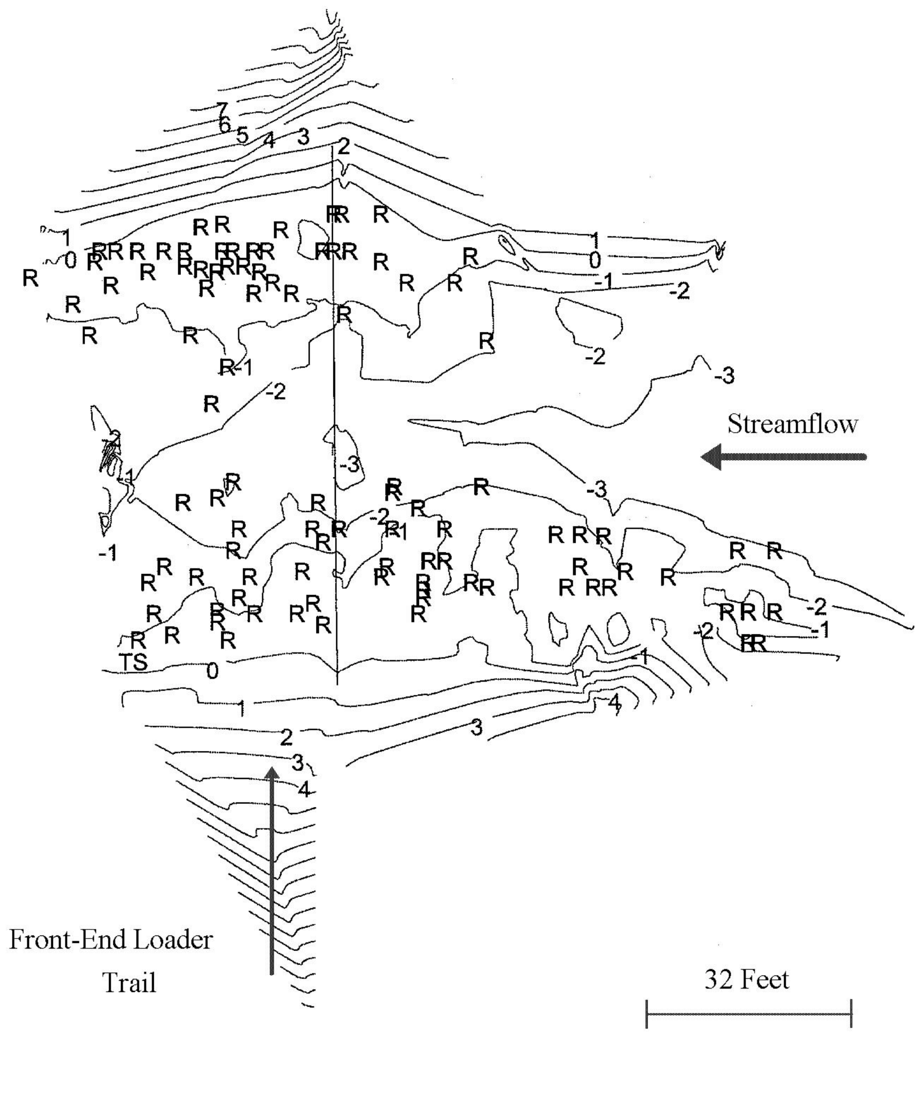


Figure 1. Contour map of Riffle DFG2 at rivermile 58.0 on the Stanislaus River showing streambed elevations measured on 14 December 1999, which was one year after gravel addition. The map shows the locations of chinook salmon redds (R), the transect (vertical line), and total station (TS). The water surface elevation was 0.3325 feet at the transect in December 1999 when flow releases were 350 cfs. The elevation of the top of the transect pin on river left is 5.05 feet.

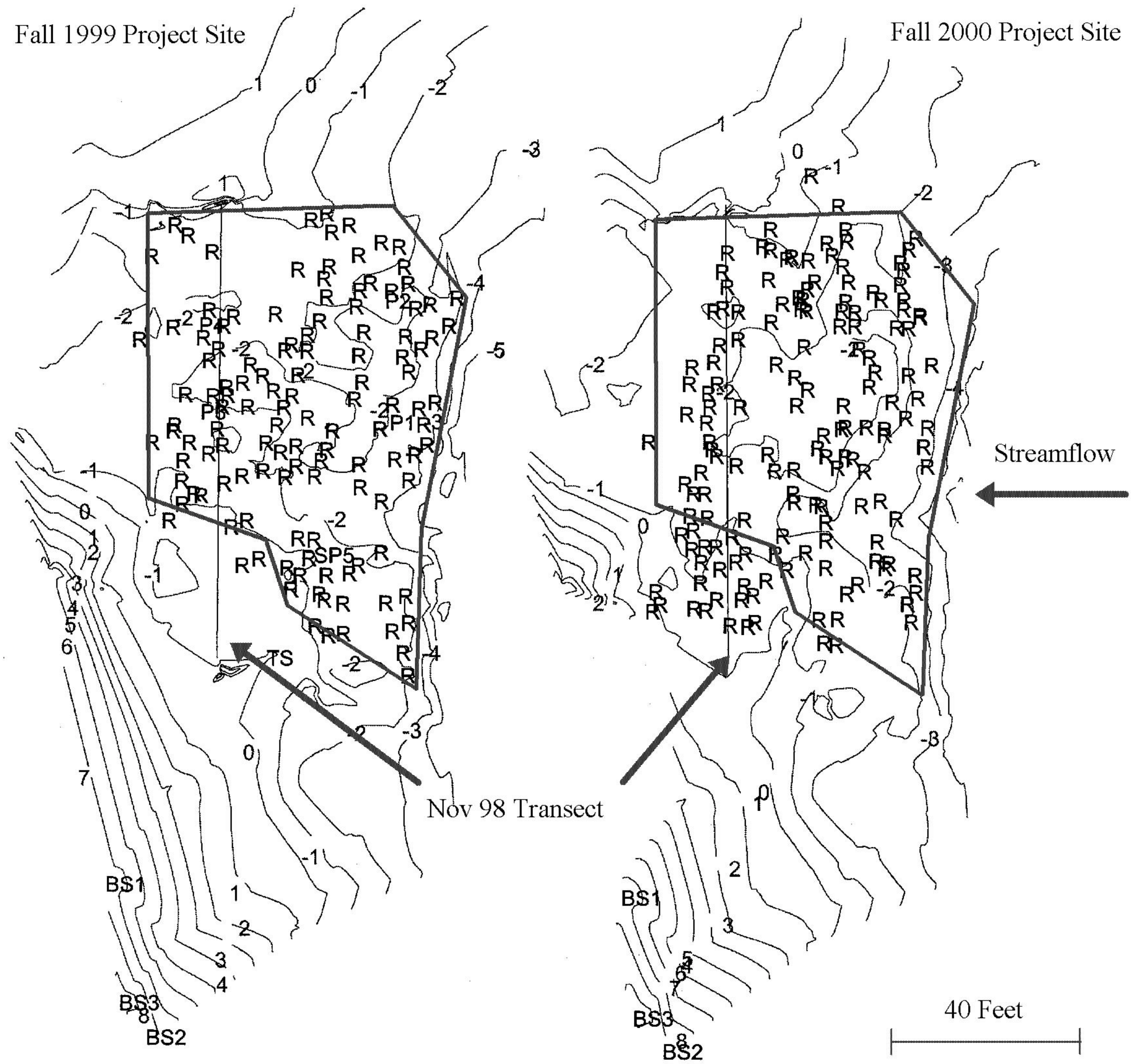


Figure 2 Contour maps of Riffle TMA on the Stanislaus River at rivermile 56.8 showing post-project streambed elevations measured on 3 December 1999 (left) and 22 September 2000 (right). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (left) and 2000 (right), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.395 feet in December 1999 when flow releases from Goodwin Dam were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 7.56 feet, BS2 is 8.06 feet, and BS3 is 9.425 feet.

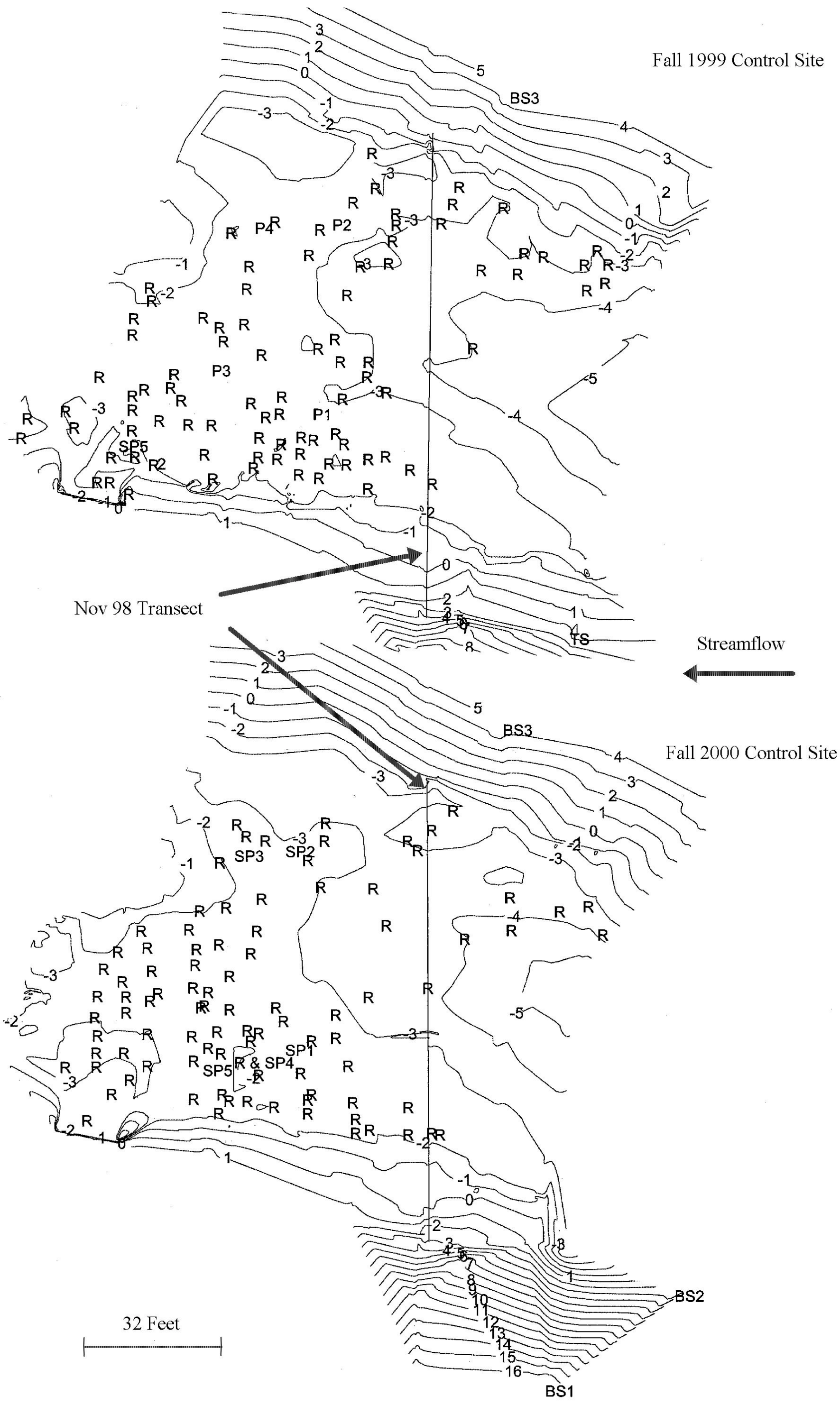


Figure 3. Contour maps of Riffle TM1 at rivermile 56.6 on the Stanislaus River showing post-project streambed elevations measured on 13 December 1999 (upper) and 21 September 2000 (lower). The map shows the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical line), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.98 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 16.51 feet, BS2 is 2.755 feet, and BS3 is 4.72 feet.

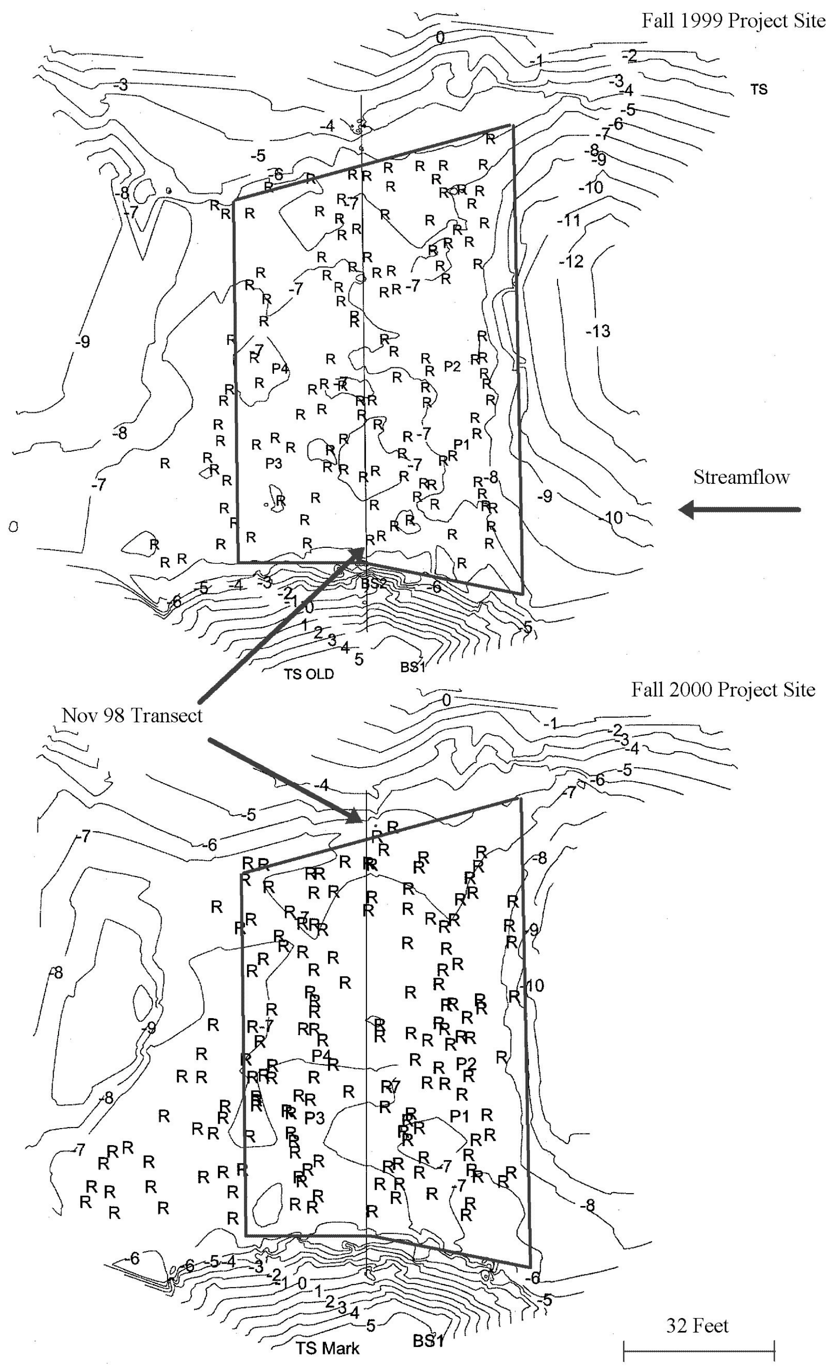


Figure 4. Contour maps of Riffle R1 at rivermile 54.55 on the Stanislaus River showing post-project streambed elevations on 14 December 1999 (upper) and 18 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 and 2000, the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -5.42 feet in December 1999 at flow releases of 350 cfs. The elevation of the marked rock at backsight 1 (BS1) is 5.825 feet, the pin at BS3 is 4.36 feet, and the pin at BS4 is 7.65 feet. BS2 was vandalized.

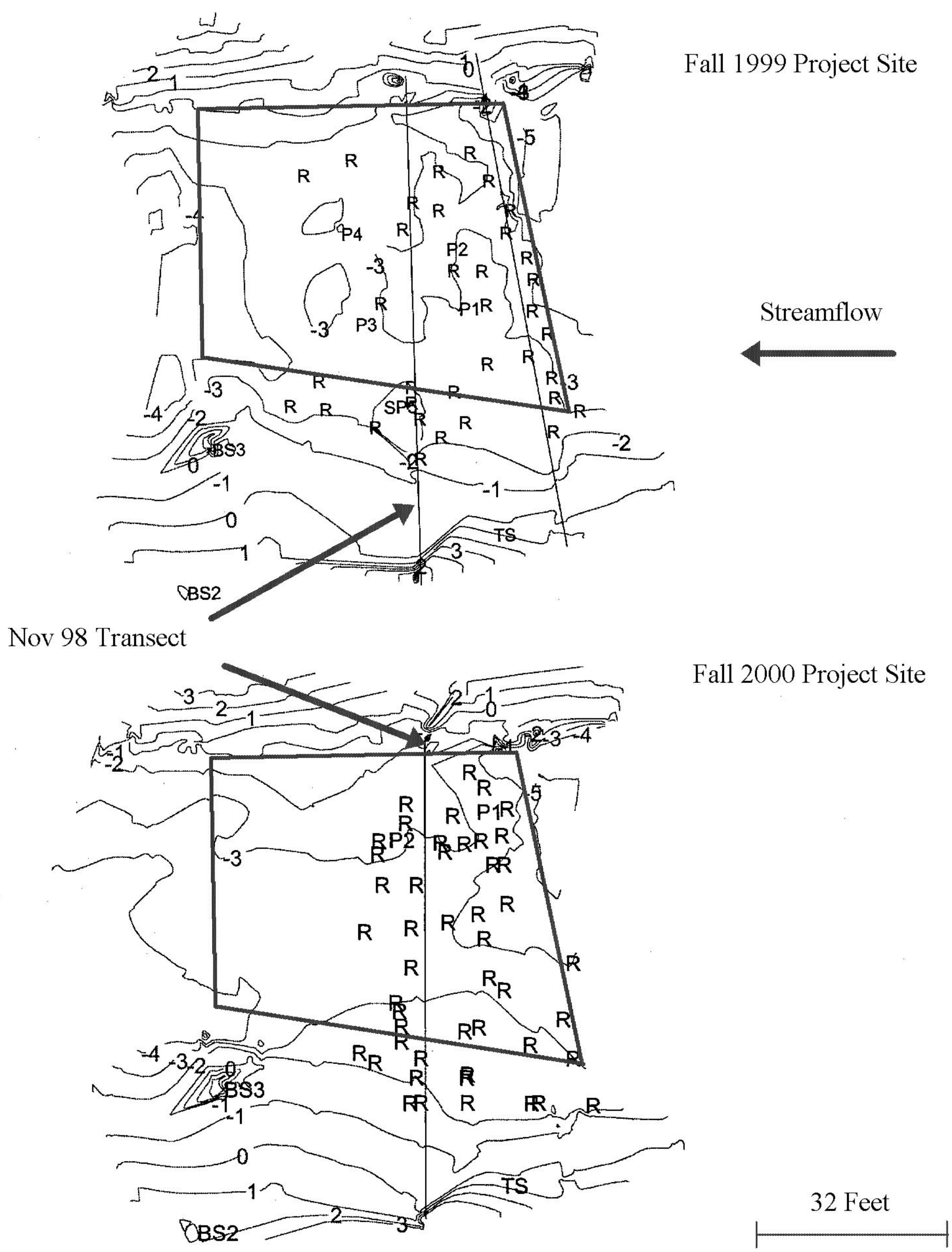


Figure 5. Contour maps of Riffle R5 at rivermile 53.9 on the Stanislaus River showing post-project elevations on 15 December 1999 (upper) and 18 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was and -1.105 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.705 feet, BS2 is 2.145 feet, and BS3 is 2.220 feet.

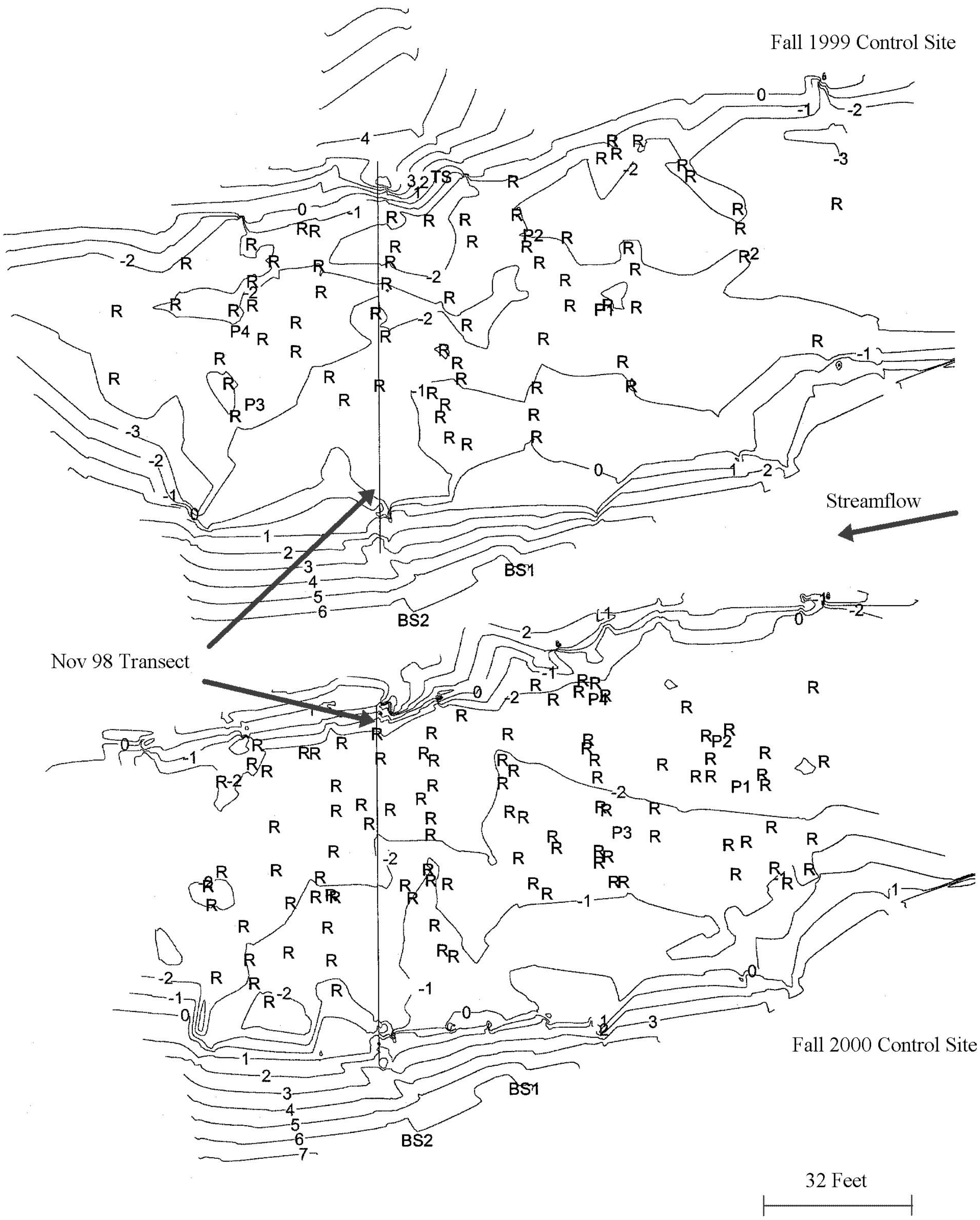


Figure 6. Contour maps of Riffle R10 at rivermile 53.5 on the Stanislaus River showing streambed elevations measured on 23 August 1999 (upper) and 24 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and fall 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was 0.815 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.355 feet, BS2 is 6.44 feet, and BS3 is 14.070 feet.

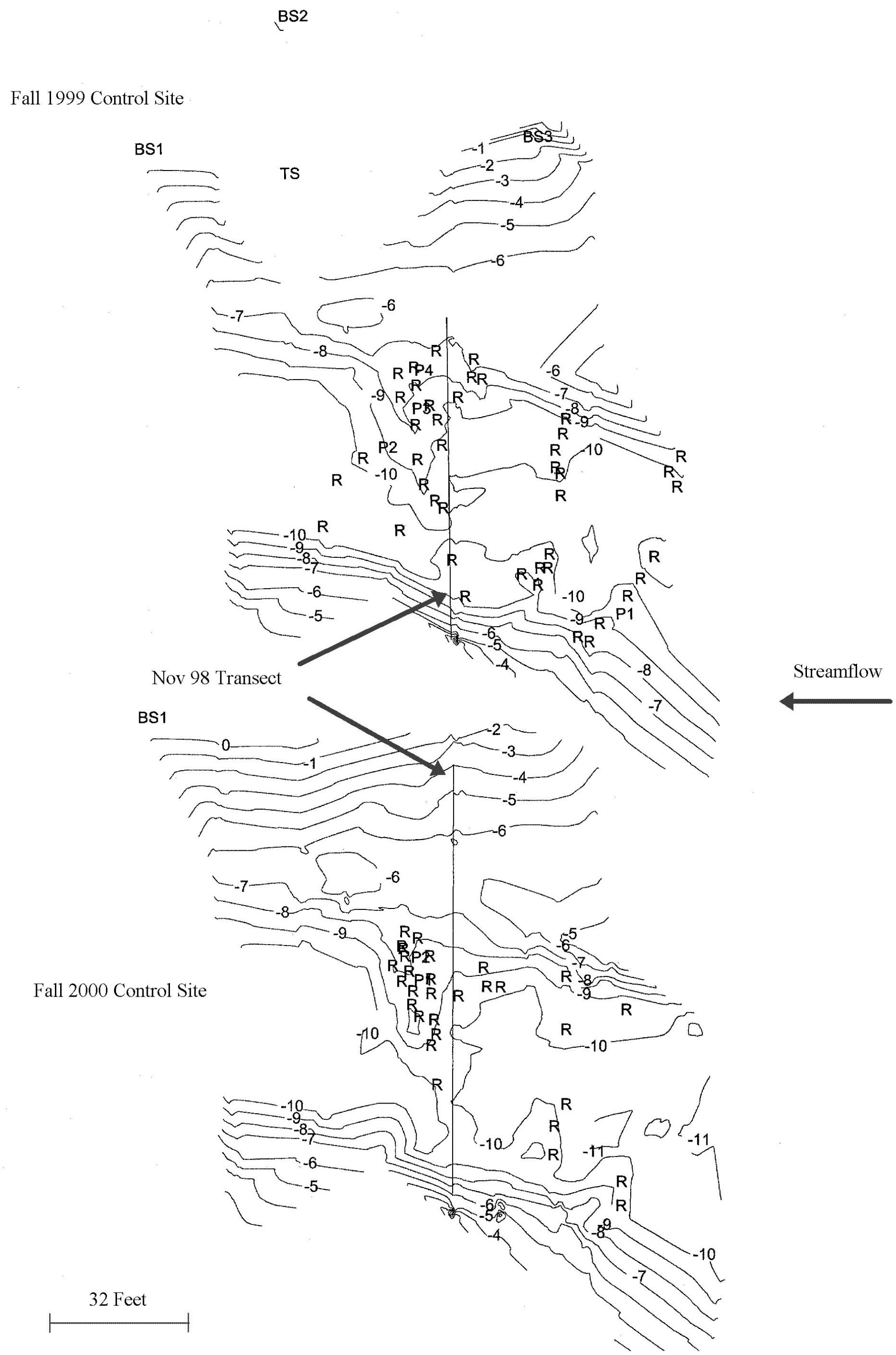


Figure 7. Contour maps of Riffle R12 at rivermile 53.3 on the Stanislaus River showing streambed elevations on 14 December 1999 (upper) and 30 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -6.35 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.785 feet, BS2 is 5.20 feet, and BS3 is -1.415 feet.

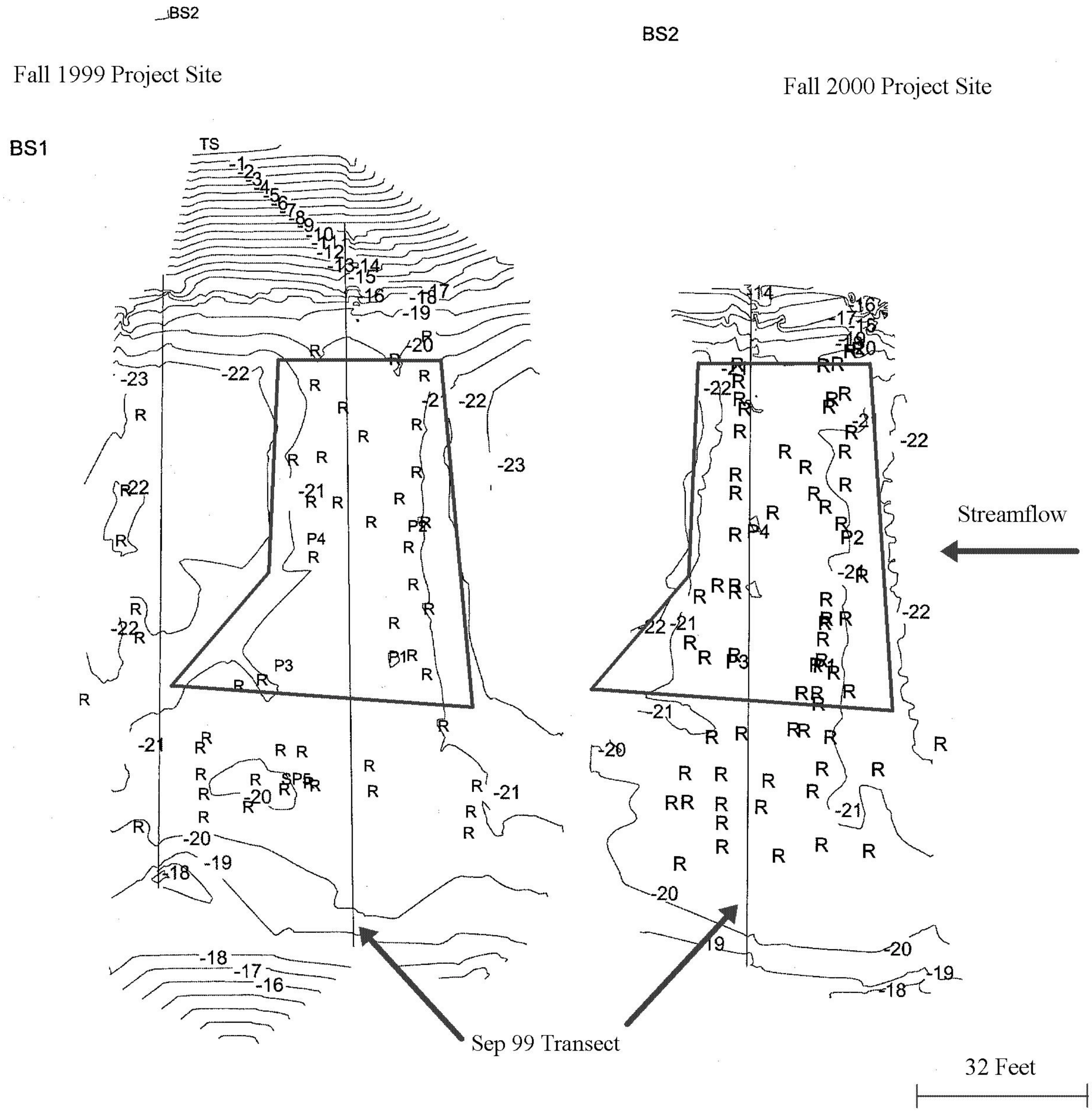


Figure 8. Contour maps of Riffle R12A at rivermile 52.82 on the Stanislaus River showing post-project streambed elevations on 12 December 1999 (upper) and 25 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -18.90 feet in December 1999, when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.355 feet and BS2 is 0.975 feet.

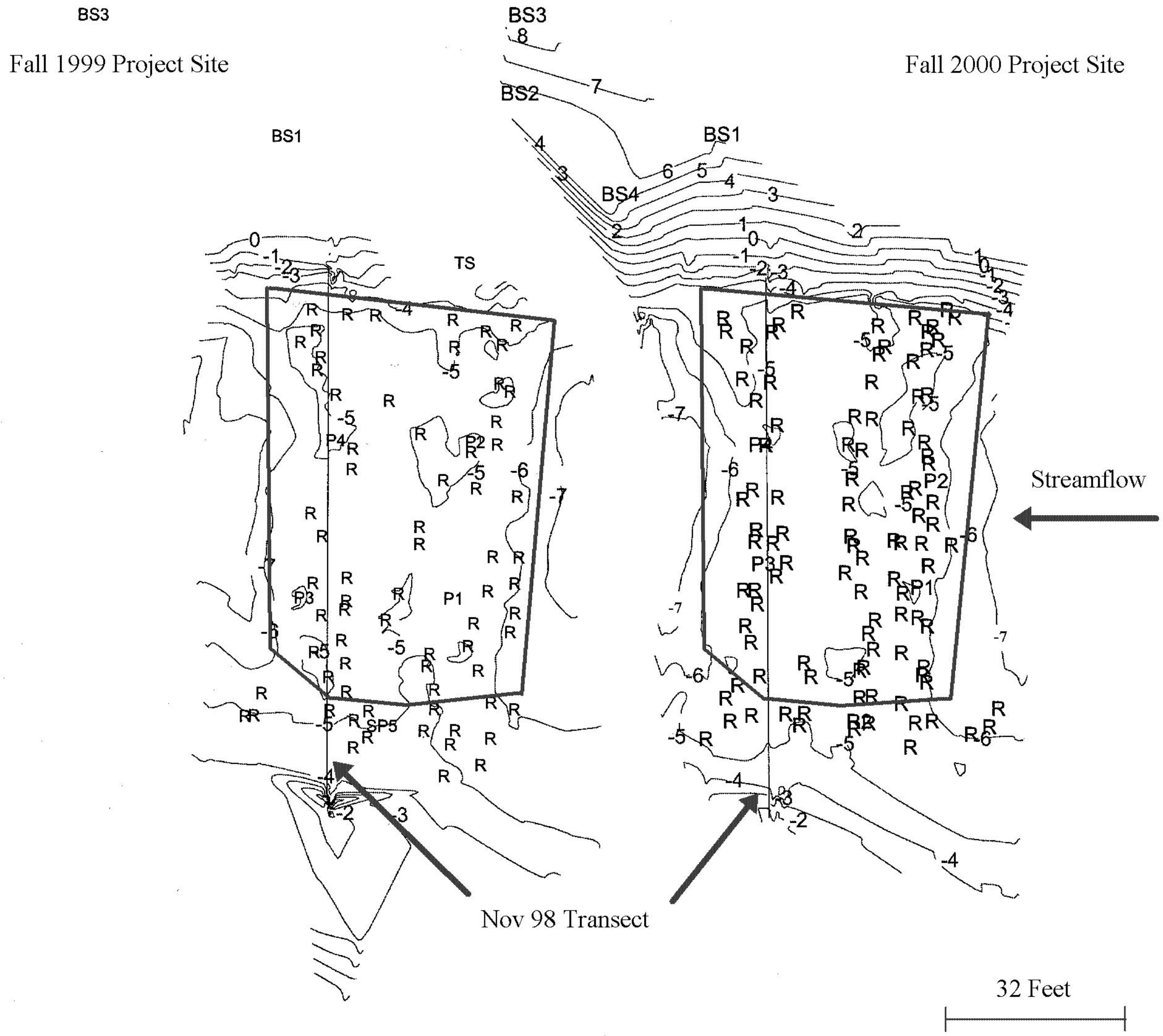


Figure 9. Contour maps of Riffle R12B at rivermile 52.77 on the Stanislaus River showing post-project streambed elevations on 12 December 1999 (upper) and 25 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -3.713 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 6.375 feet, BS3 is 8.430 feet, and BS4 is 5.825 feet.

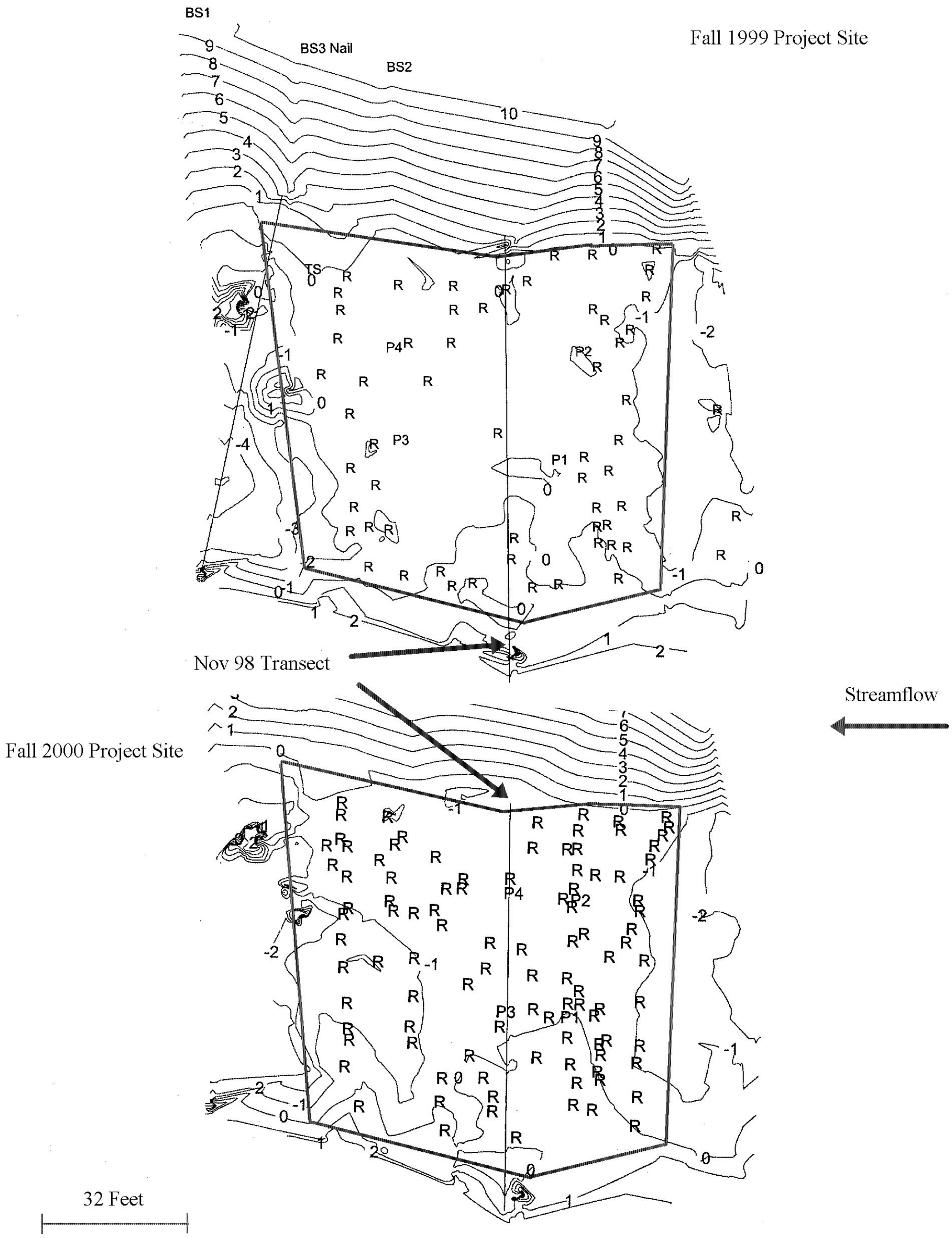


Figure 10. Contour maps of Riffle R13 at rivermile 52.73 on the Stanislaus River showing post-project streambed elevations on 12 December 1999 (upper) and 25 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was 1.085 feet in December 1999 when flows were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 9.715 feet, BS2 is 10.89 feet, and the nail at BS3 is 10.335 feet.

Figure 11. Contour maps of Riffle R14 at rivermile 52.6 on the Stanislaus River showing post-project streambed elevations on 11 December 1999 (upper) and 25 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and 9 piezometers (P). The water surface elevation at the transect was -2.72 feet in December 1999 when flows were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is -0.735 feet, BS2 is 0.53 feet, and BS4 is 12.980 feet.

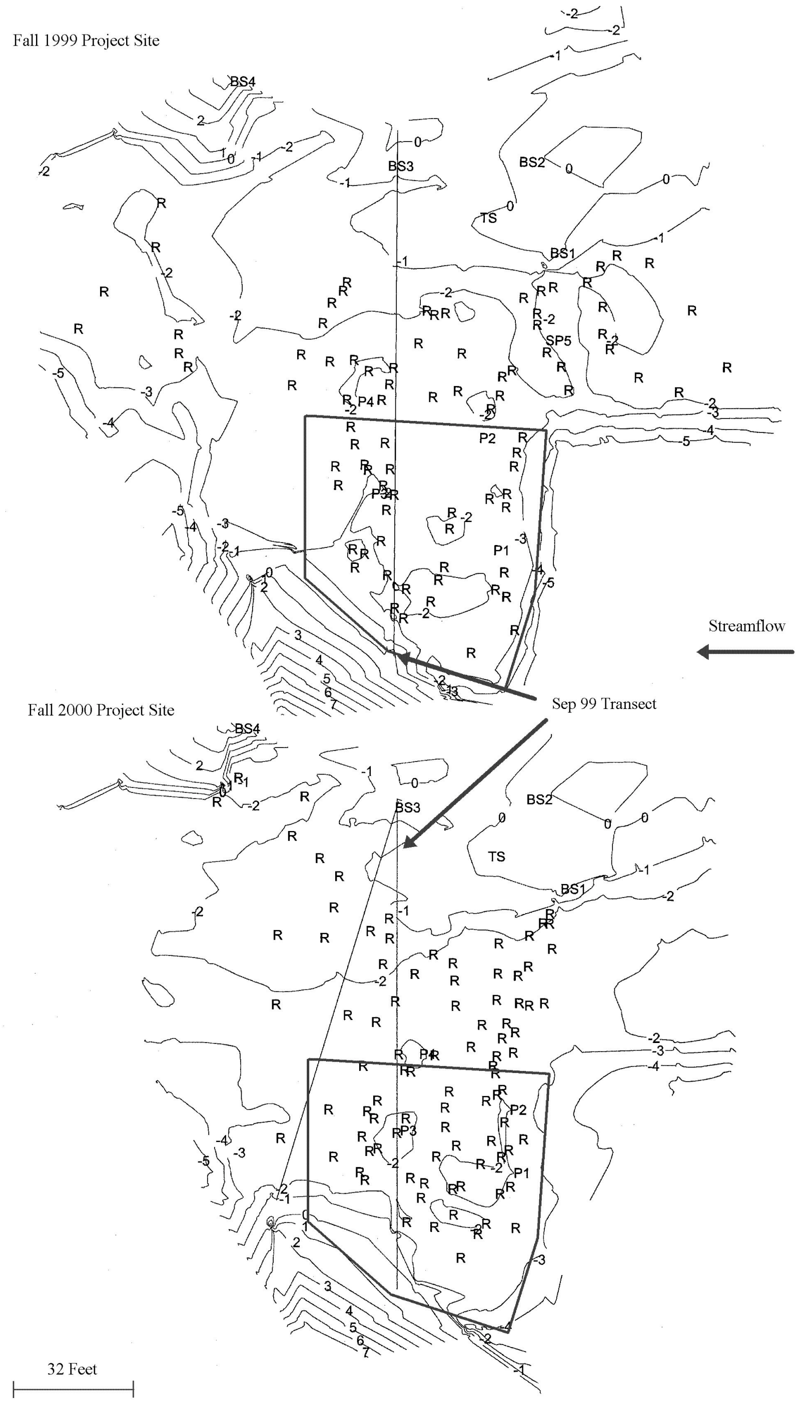


Figure 12. Contour maps of Riffle R14A at rivermile 52.57 on the Stanislaus River showing post-project streambed elevations on 11 December 1999 (upper) and 26 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.805 feet in December 1999 when flows were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 0.465 ft, BS2 is 0.56 ft, BS3 is -0.060 ft, and BS4 is 4.410 ft.

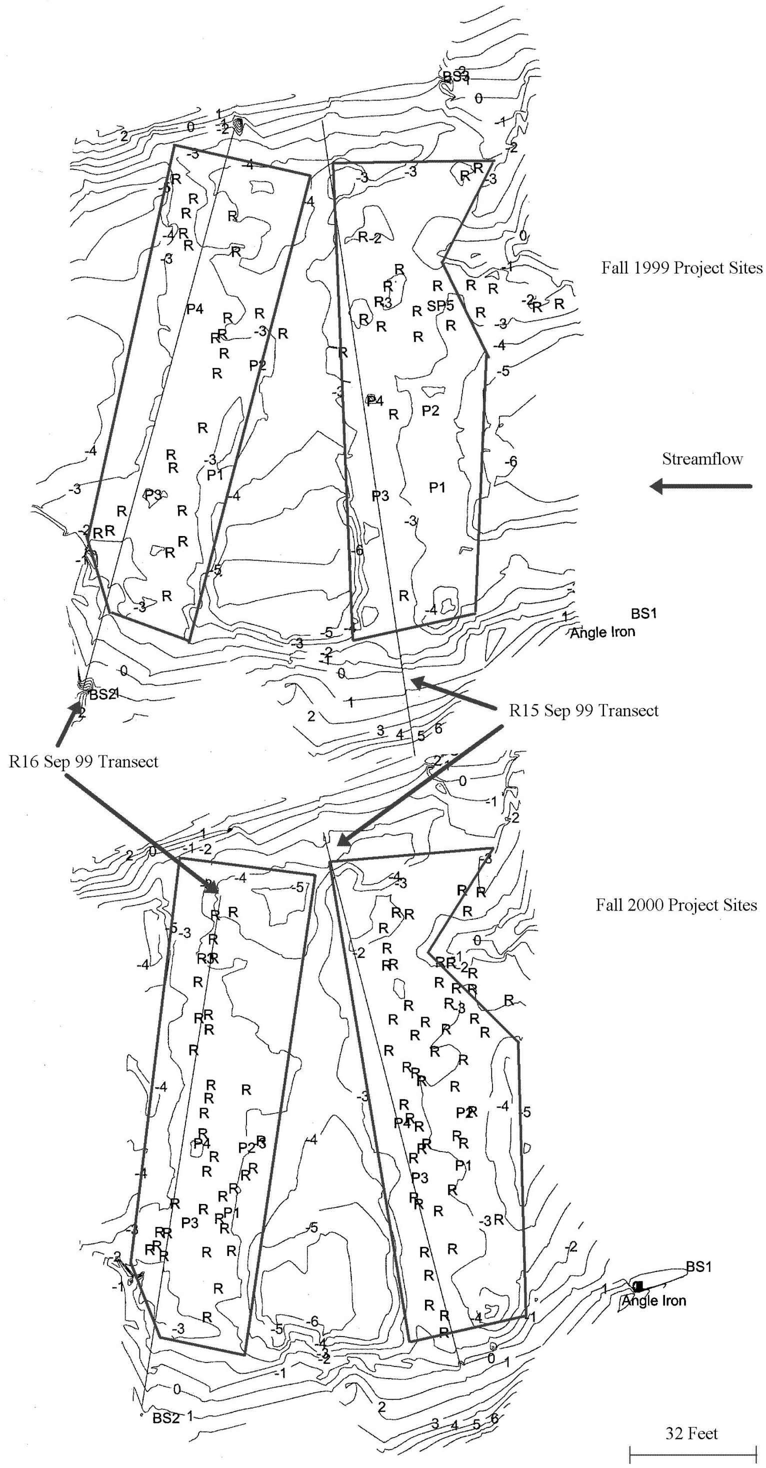


Figure 13. Contour maps of riffles R15 (right) and R16 (left) at rivermile 52.5 on the Stanislaus River showing post-project streambed elevations on 10 December 1999 (upper) and 27-28 September 2000 (lower). The maps show the locations of gravel placement (polygons), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation was -1.038 feet at the R15 transect and -1.125 feet at the R16 transect (left) in December 1999, when flow releases were 350 cfs. The elevation of the top of the metal pin at backsight 1 (BS1) is 4.155 feet, BS2 is 1.13 feet, and BS3 is 1.840 feet.

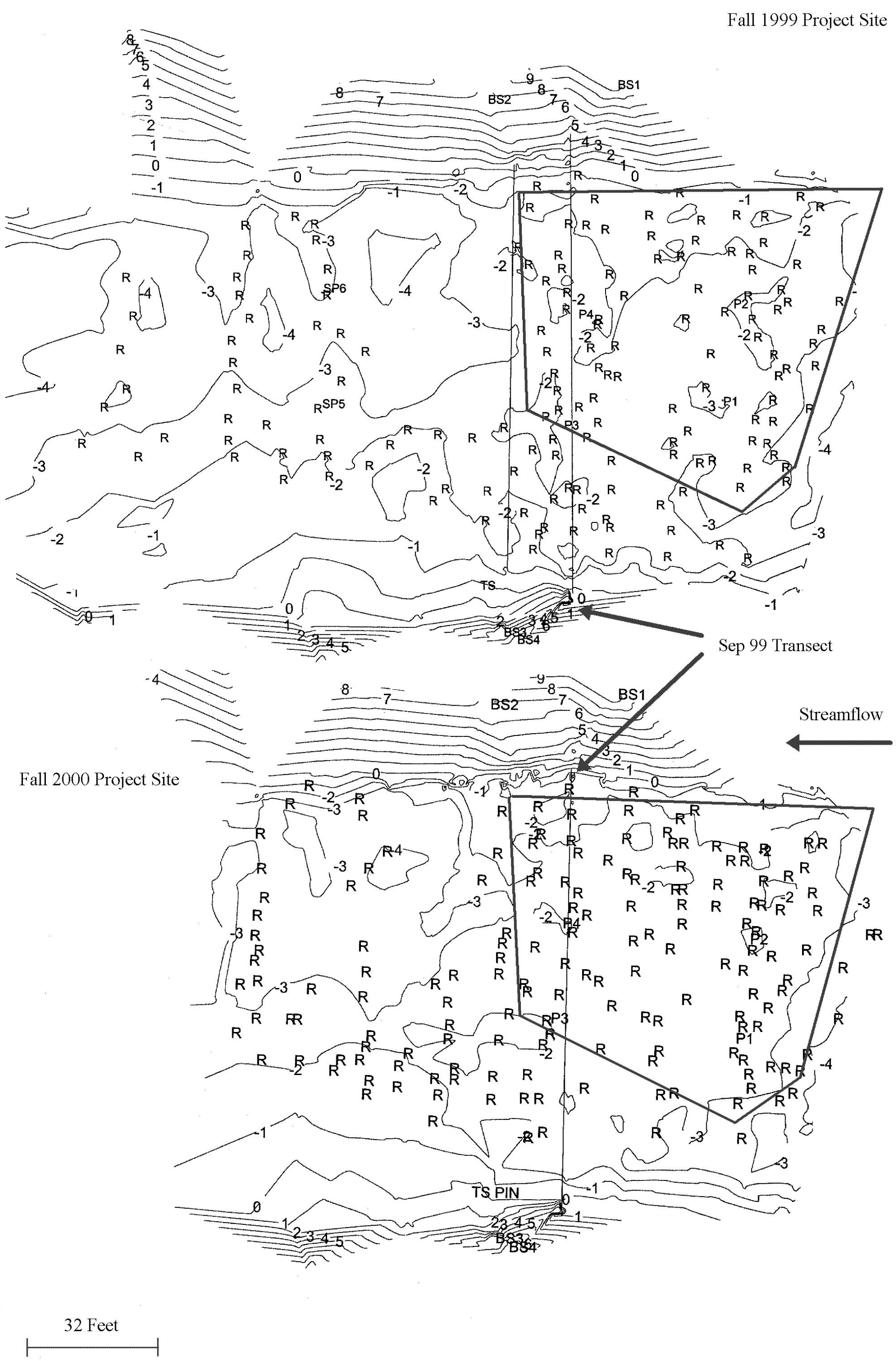


Figure 14. Contour maps of Riffle R19 at rivermile 52.13 on the Stanislaus River showing post-project streambed elevations on 8 December 1999 (upper) and 28 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.72 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 9.04 feet, BS2 is 6.755 feet, BS3 is 6.530 feet, and BS4 is 8.665 feet.

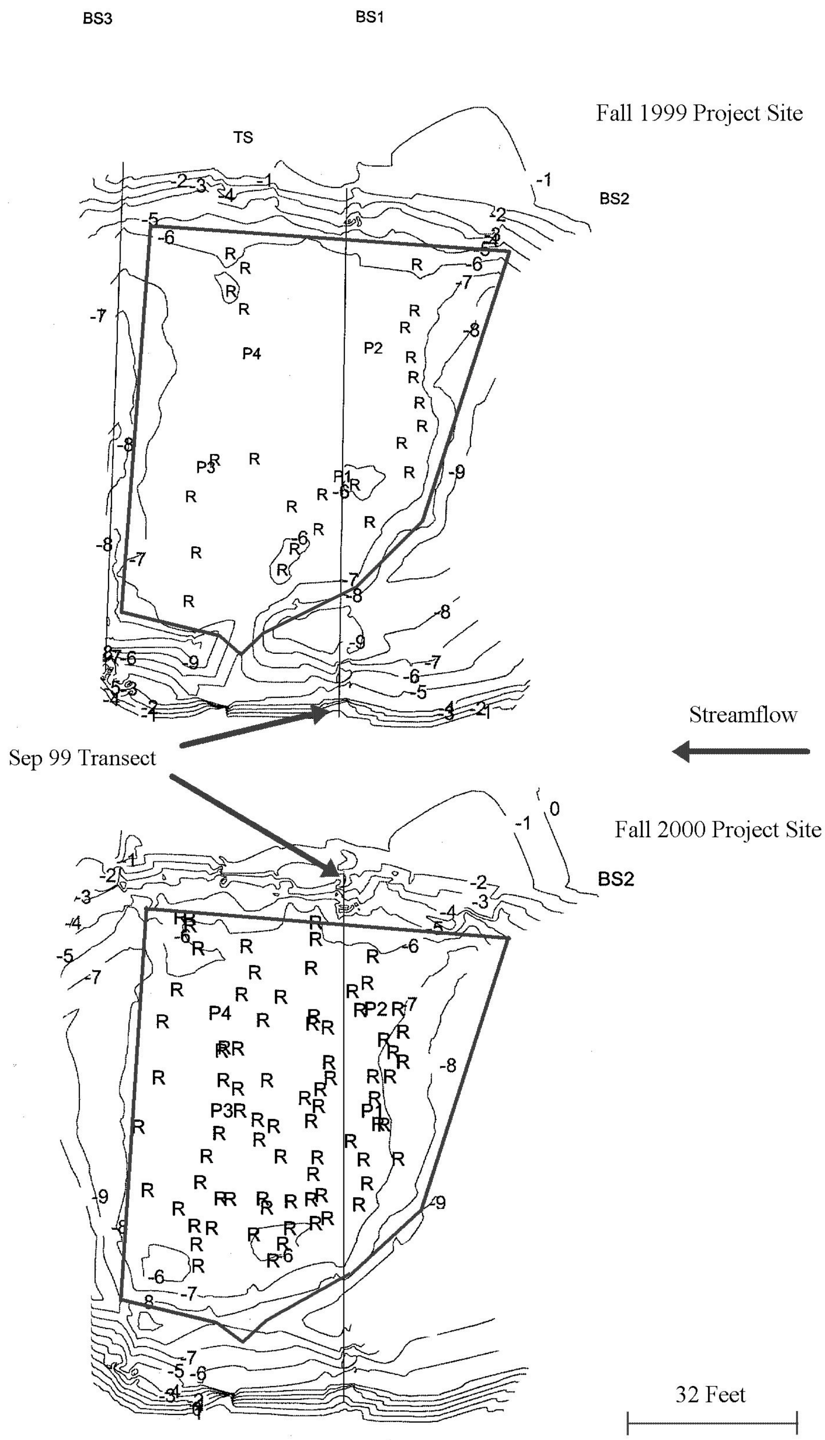


Figure 15. Contour maps of Riffle R19A at rivermile 52.06 on the Stanislaus River showing post-project streambed elevations on 8 December 1999 (upper) and 27 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -4.59 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is -0.125 feet, BS2 is 0.71 feet, and BS3 was 1.180 feet.

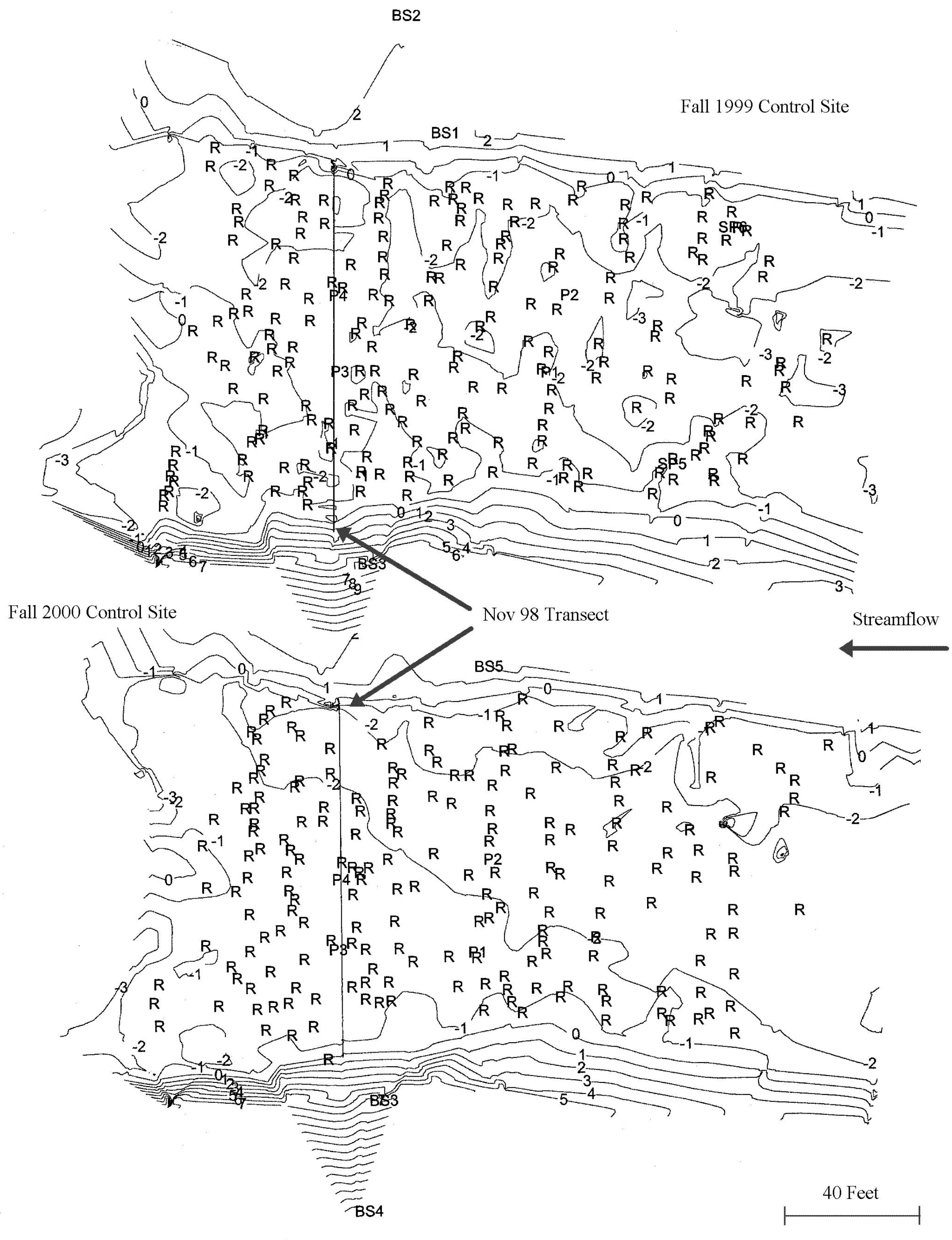


Figure 16. Contour maps of Riffle R20 at rivermile 51.8 on the Stanislaus River on 7 December 1999 (upper) and 28 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.08 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.605 feet, BS2 is 2.121 feet, BS3 is 7.370 feet, and BS4 is 19.505 feet.

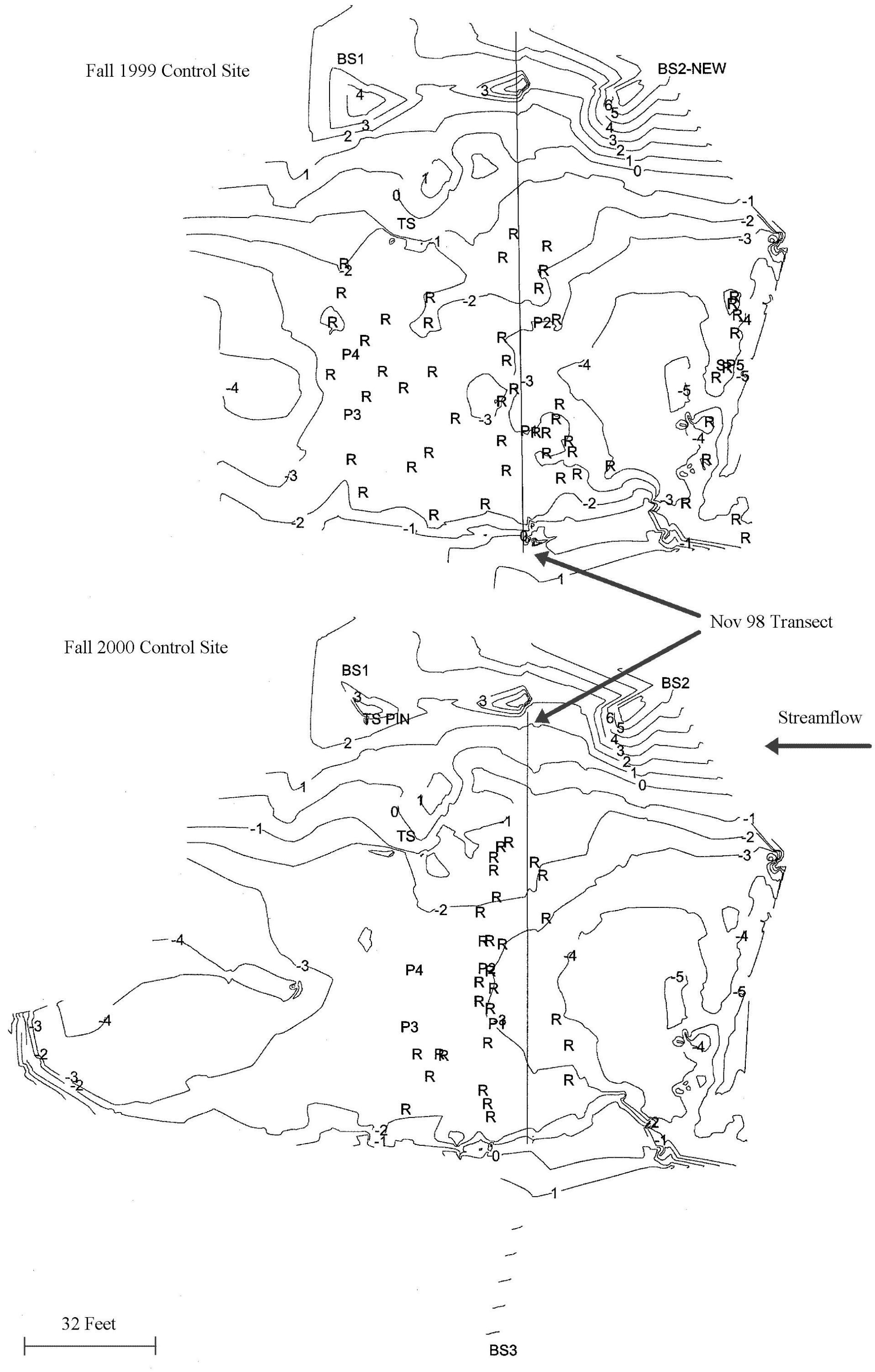


Figure 17. Contour maps of Riffle R27 at rivermile 50.8 on the Stanislaus River showing streambed elevations on 6 December 1999 (upper) and 19 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical line), total stations (TS), and piezometers (P). The water surface elevation at the transect was -0.75 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 2.95 feet and BS3 is 6.69 feet.

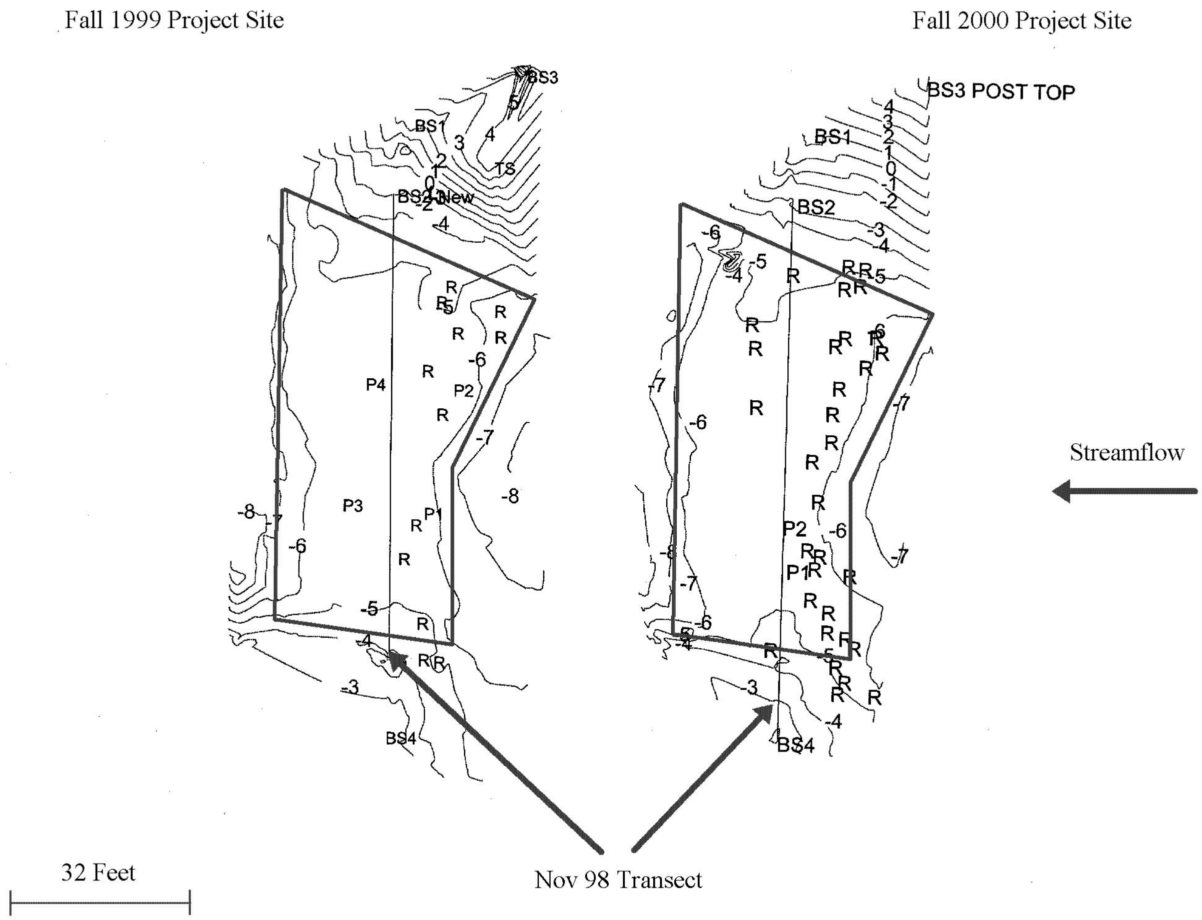


Figure 18. Contour maps of Riffle R28A at rivermile 50.2 on the Stanislaus River showing post-project streambed elevations on 6 December 1999 (upper) and 19 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -3.78 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.52 feet, a new BS2 is -2.725 feet, and BS3 is 6.10 feet.

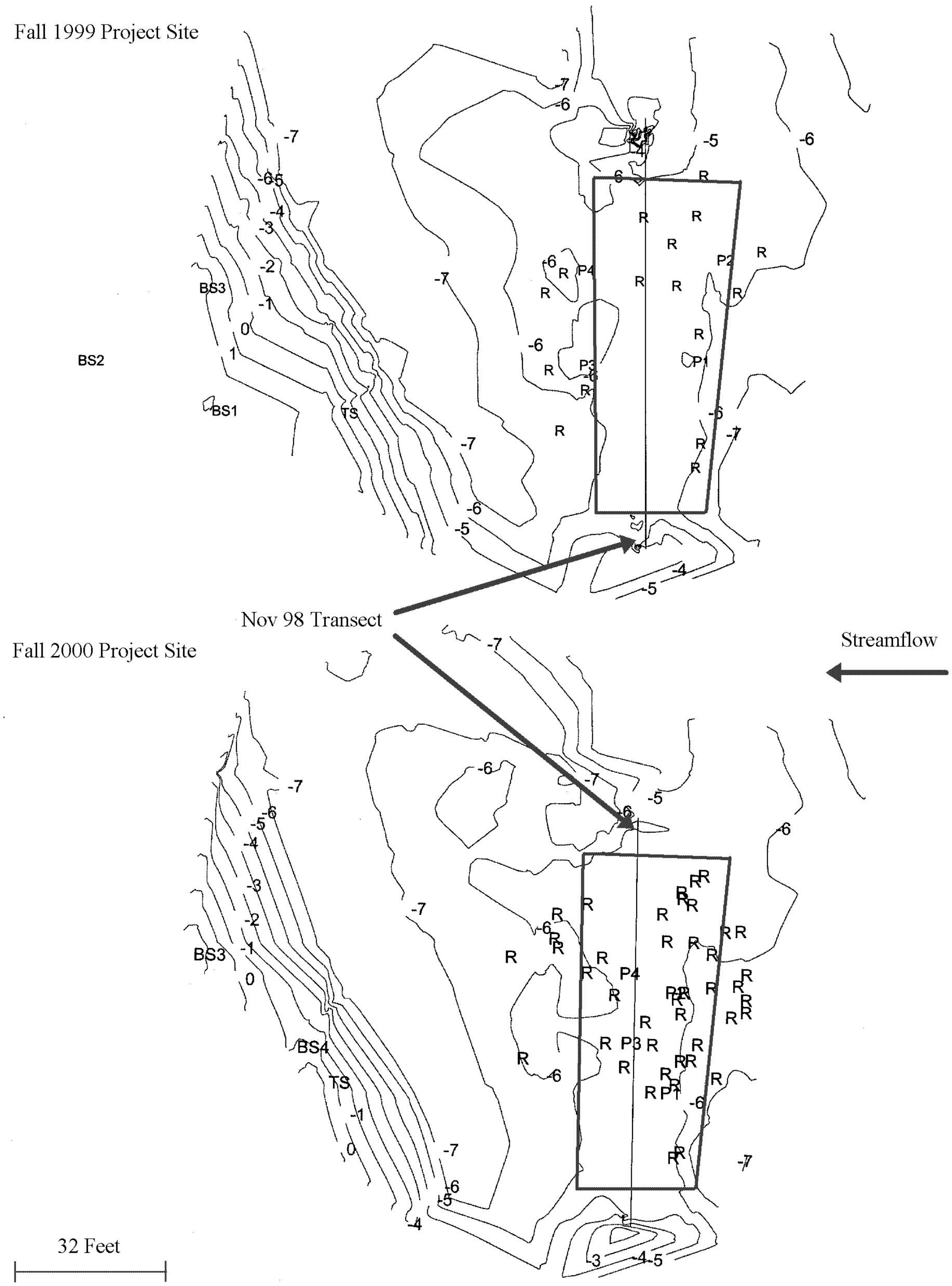


Figure 19. Contour maps of Riffle R29 at rivermile 49.75 on the Stanislaus River showing post-project streambed elevations on 6 December 1999 (upper) and 19 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), the transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -4.56 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 1.995 feet, BS2 is 1.88 feet, and BS3 is 1.460 feet.

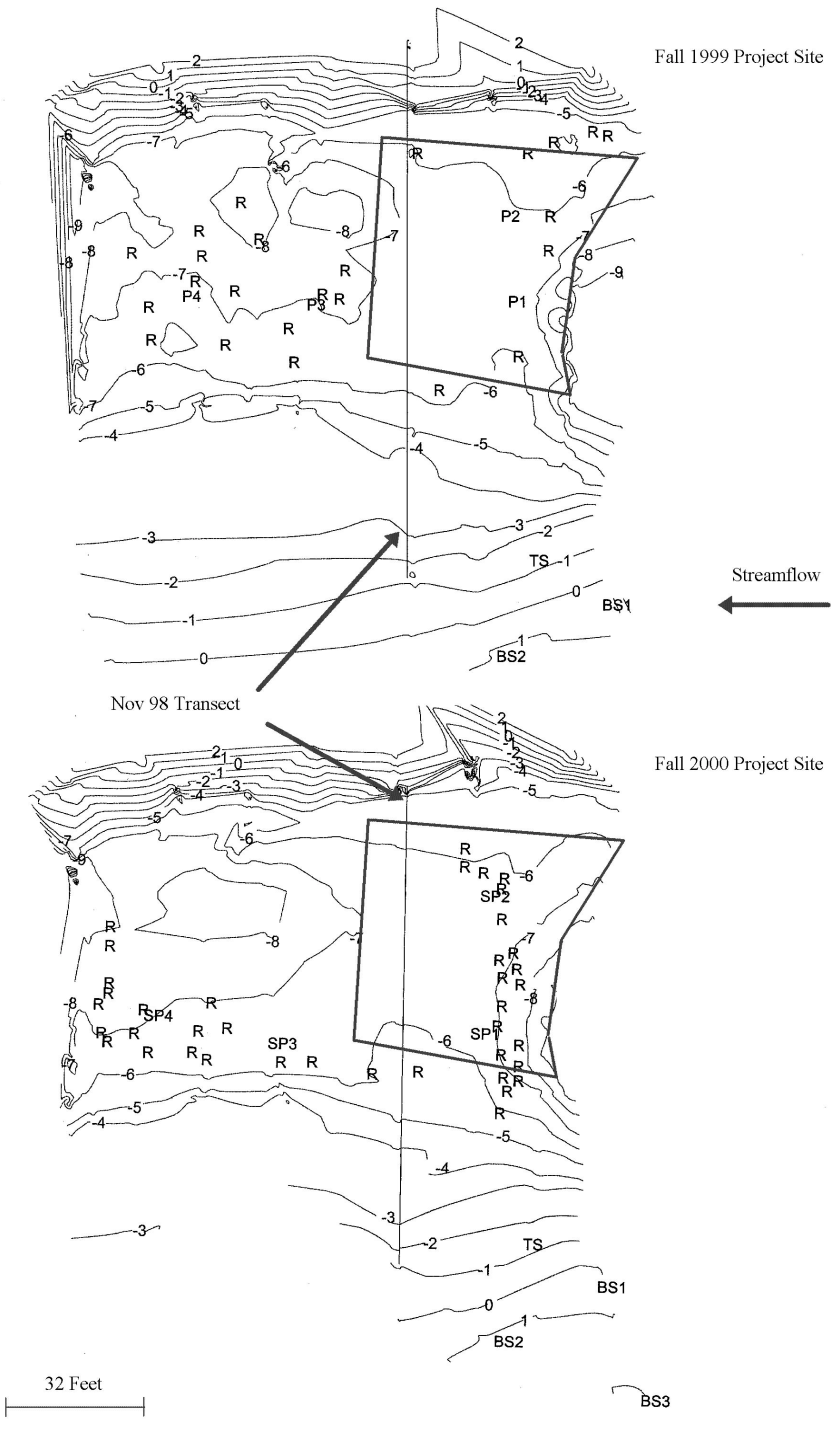


Figure 20. Contour maps of Riffle R43 at rivermile 46.9 on the Stanislaus River showing post-project streambed elevations on 6 December 1999 (upper) and 17 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -5.04 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 0.70 feet, BS2 is 1.245 feet, and BS3 is 2.110 feet.

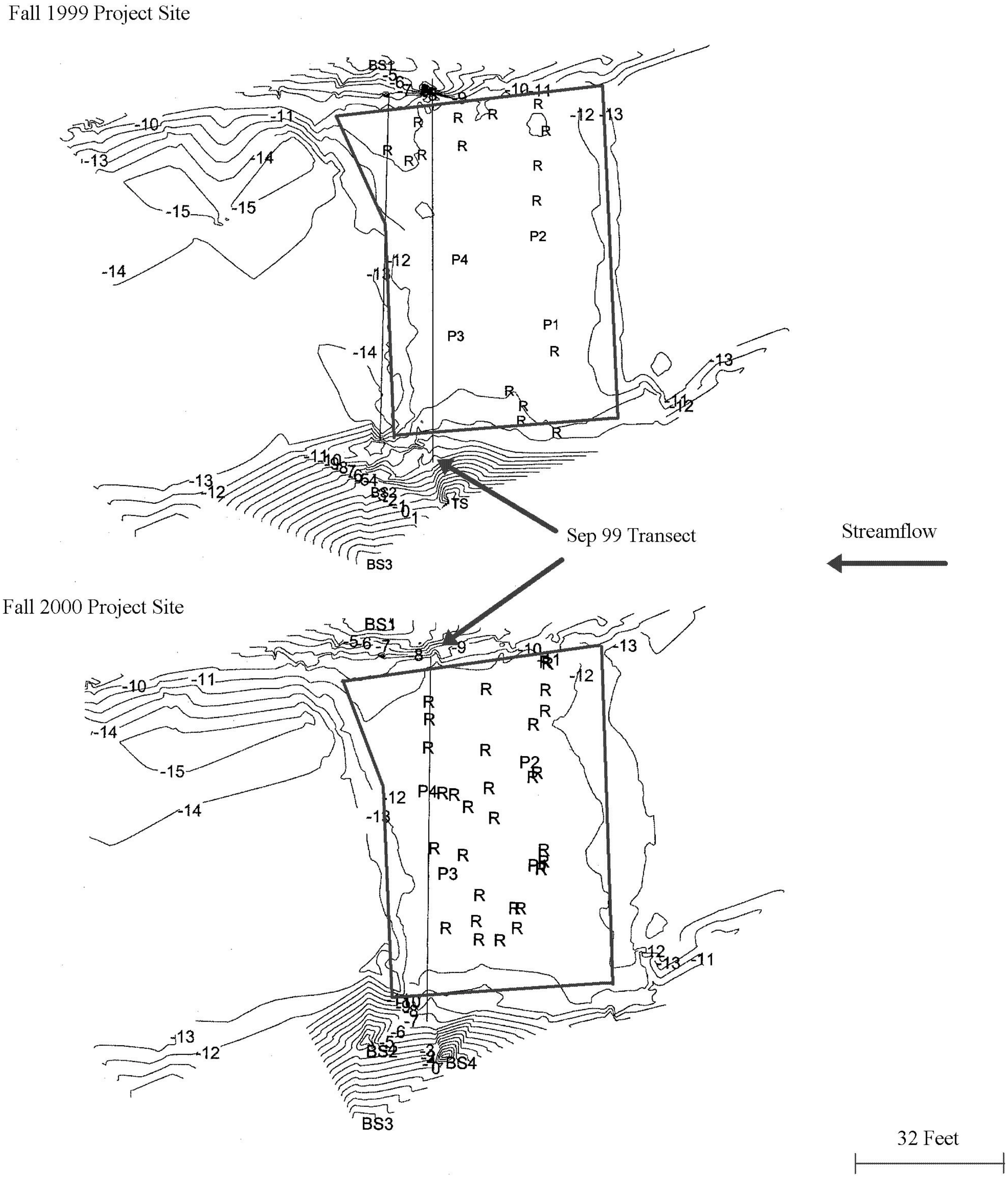


Figure 21. Contour maps of Riffle R57 at rivermile 44.6 on the Stanislaus River showing post-project streambed elevations on 5 December 1999 (upper) and 21 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -9.84 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is -2.20 feet, BS2 is -3.325 feet, and BS3 is 5.270 feet.

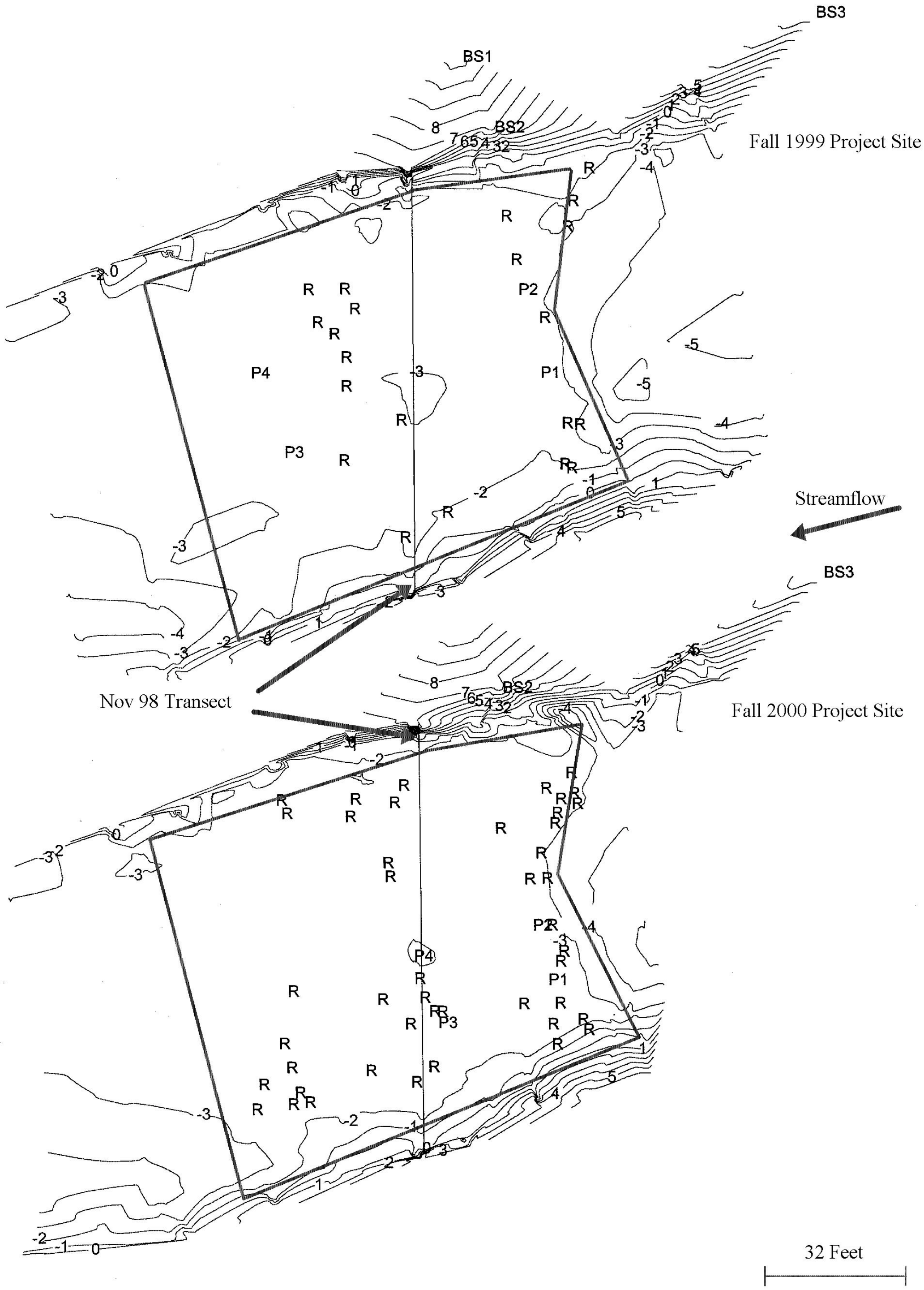


Figure 22. Contour maps of Riffle R58 at rivermile 44.5 on the Stanislaus River showing post-project streambed elevations on 4 December 1999 (upper) and 21 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -1.095 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 11.45 feet, BS2 is 7.00 feet, and BS3 is 8.785 feet.

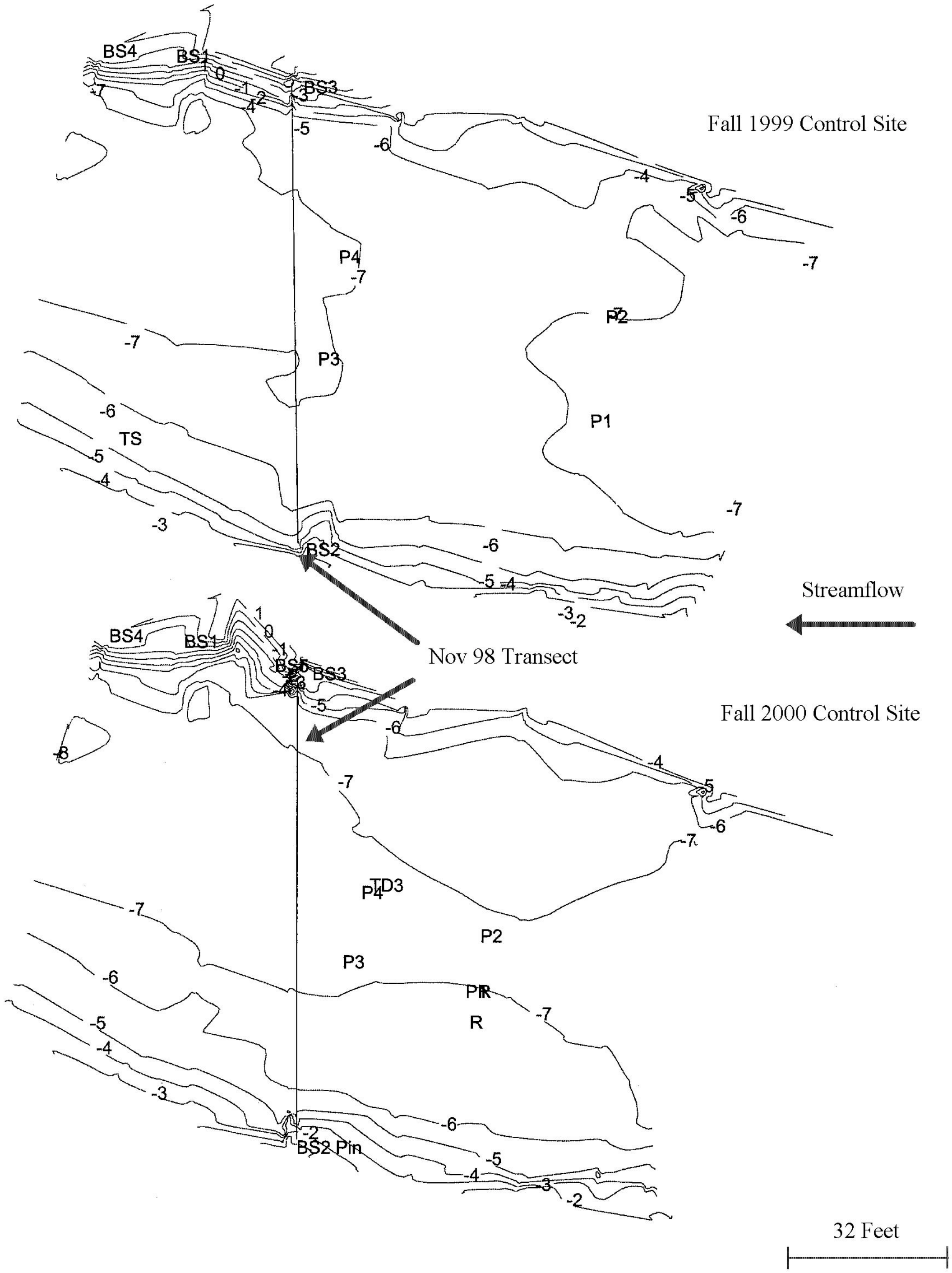


Figure 23. Contour maps of Riffle R59 at rivermile 44.4 on the Stanislaus River showing streambed elevations measured on 4 December 1999 (upper) and 21 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was -5.01 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is -1.635 feet, BS3 is -2.300 feet, and BS4 is -0.130 feet.

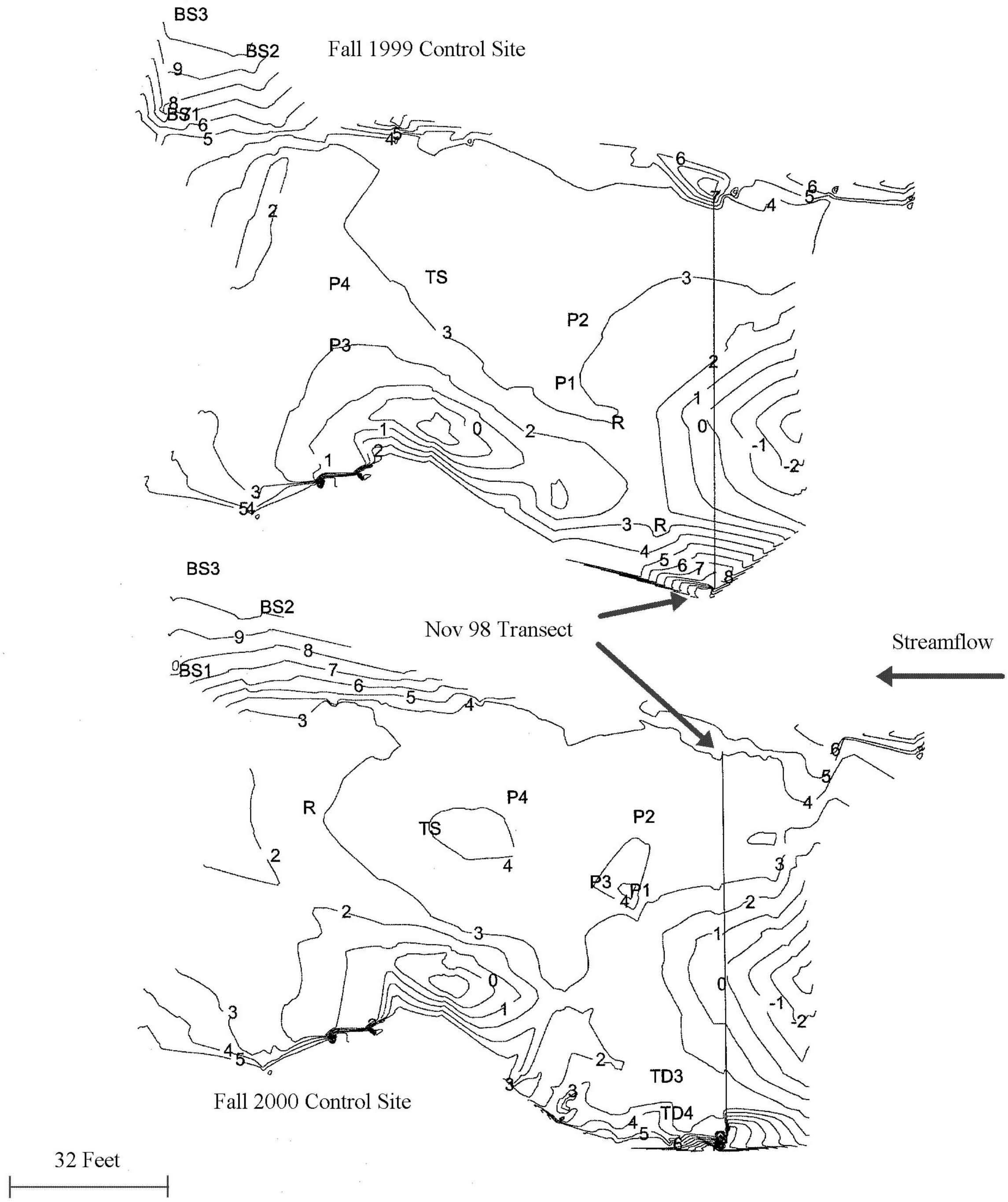


Figure 24. Contour maps of Riffle R76 at rivermile 40.35 on the Stanislaus River showing streambed elevations measured on 5 December 1999 (upper) and 29 September 2000 (lower). The maps show the locations of chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical lines), total stations (TS), and piezometers (P). The water surface elevation at the transect was 4.62 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 8.065 feet, BS2 is 10.295 feet, and BS3 is 10.760 feet.

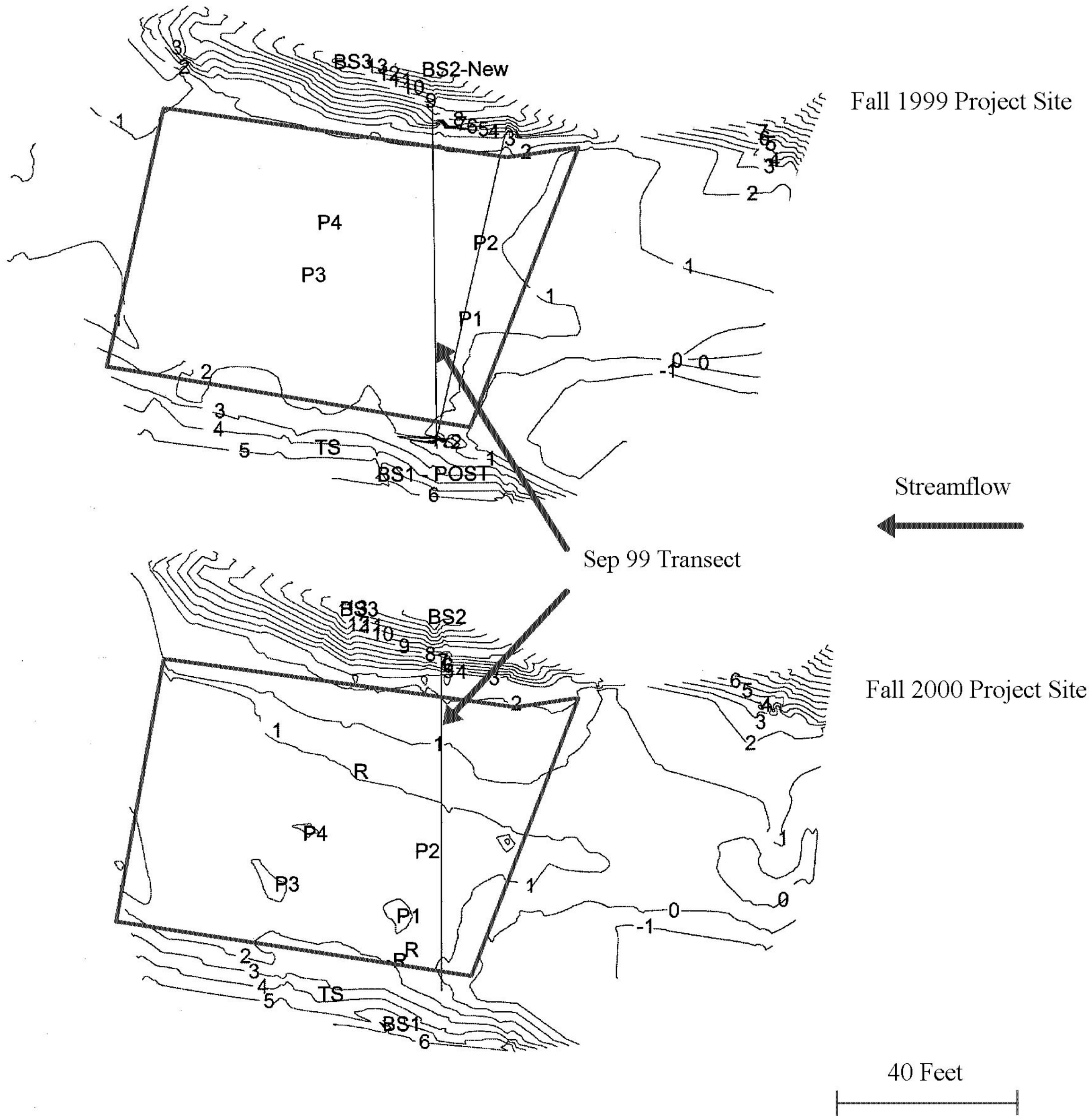
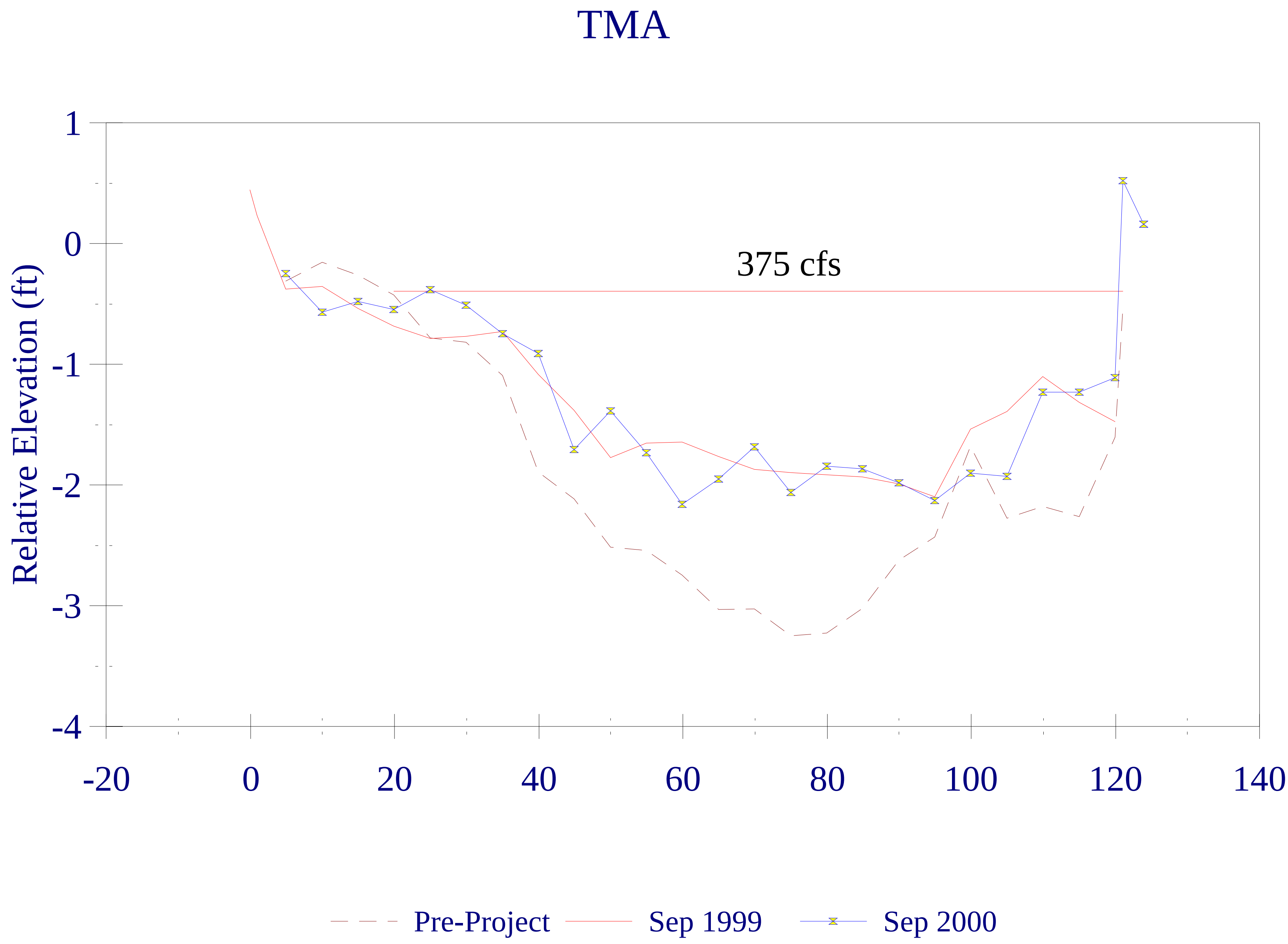


Figure 25. Contour maps of Riffle R78 at rivermile 40.2 on the Stanislaus River showing post-project streambed elevations on 5 December 1999 (upper) and 29 September 2000 (lower). The maps show the locations of gravel placement (polygon), chinook salmon redds (R) in fall 1999 (upper) and 2000 (lower), transects (vertical line), total stations (TS), and piezometers (P). The water surface elevation at the transect was 3.325 feet in December 1999 when flow releases were 350 cfs. The elevation of the top of the metal pins at backsight 1 (BS1) is 6.00 feet, a new BS2 is 15.995 feet, and BS3 is 13.07 feet.

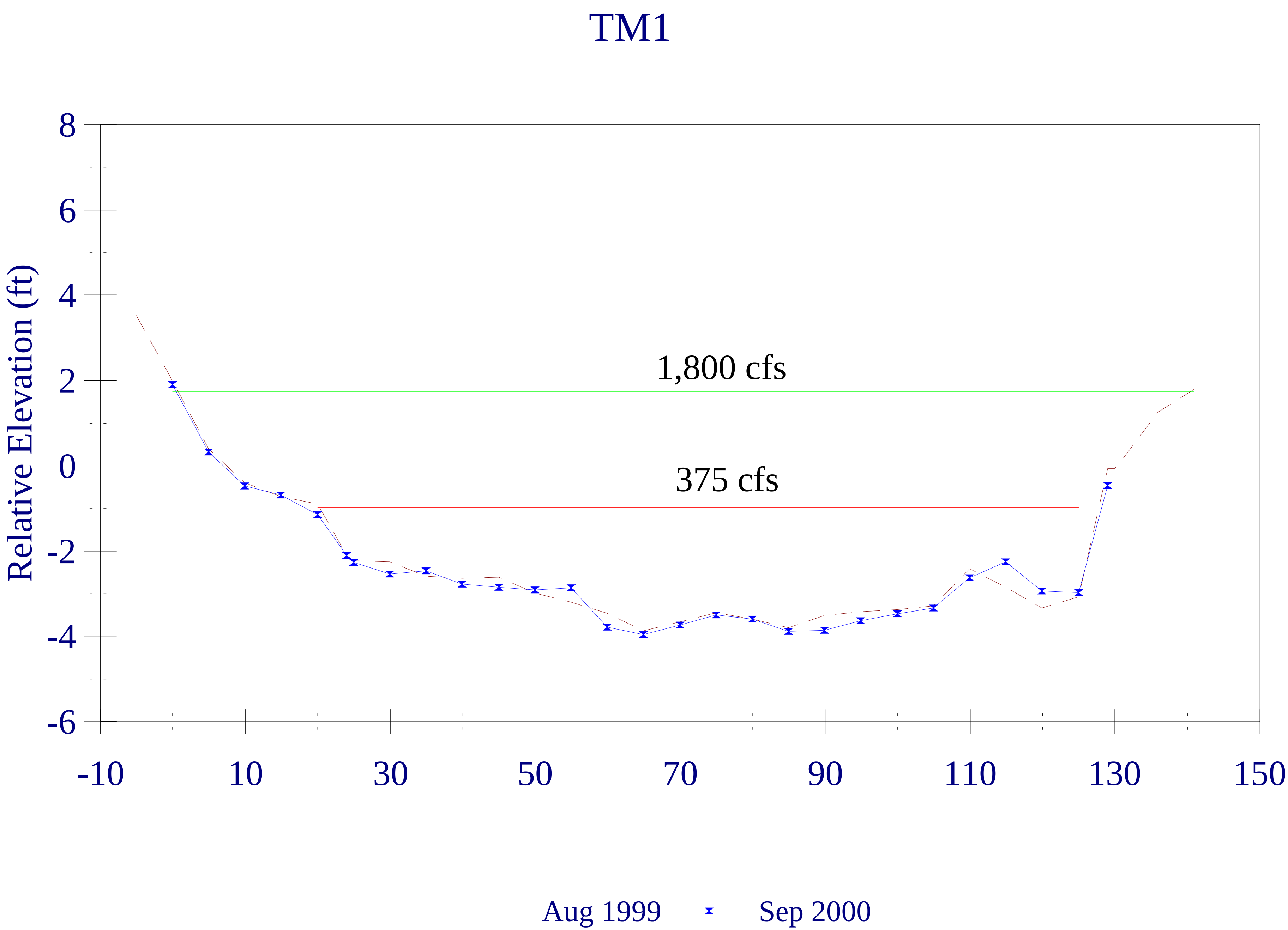
APPENDIX 4

Figures of Pre- and Post-Project Streambed Elevations

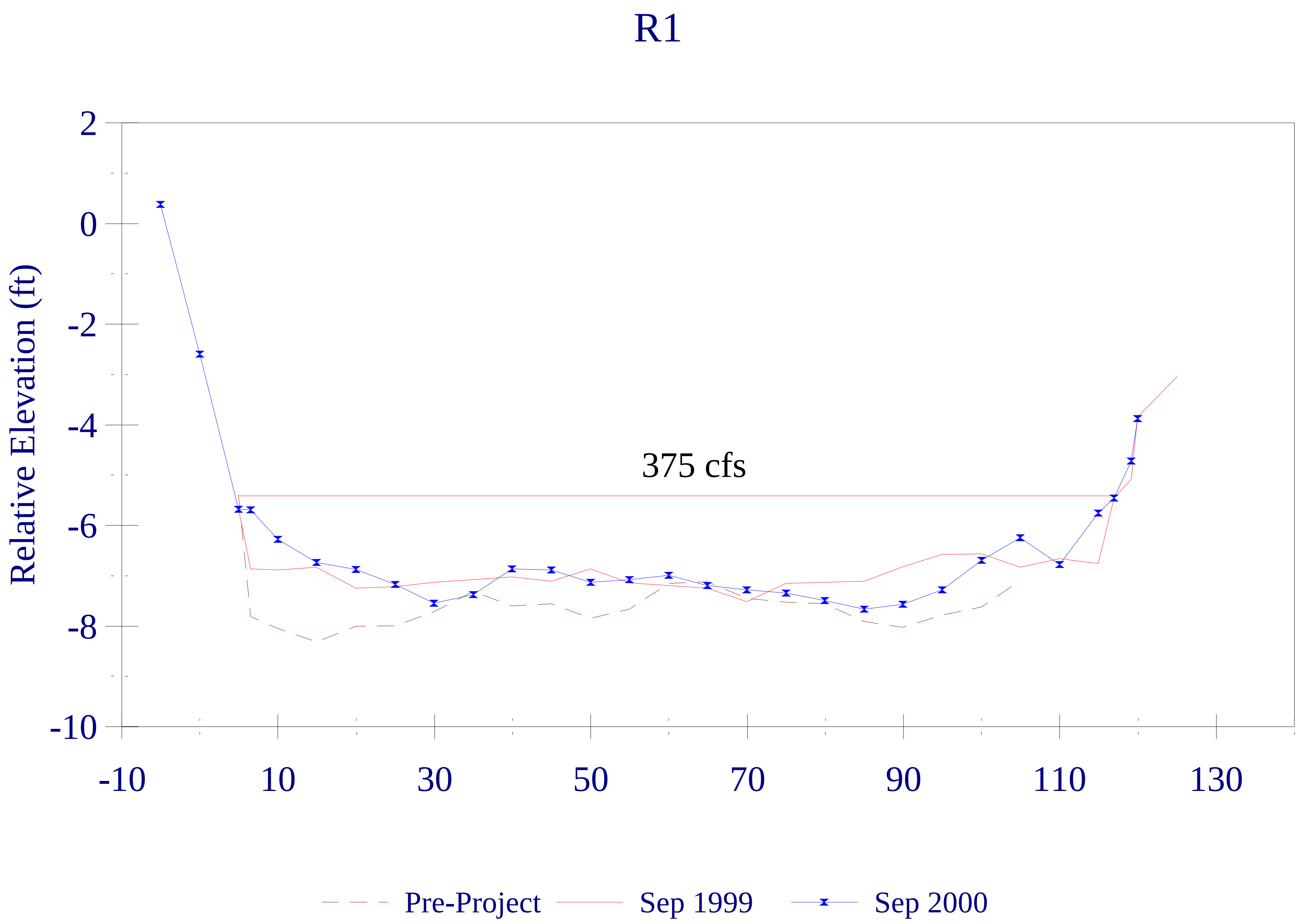
The relative streambed and water surface elevations measured at transects for pre-project conditions in August 1999 and post-project conditions in September 1999 and September 2000 are presented for 18 project riffles, which include TMA, R1, R5, R12A, R12B, R13, R14, R14A, R15, R16, R19, R19A, R28A, R29, R43, R57, R58, and R78. The relative streambed and water surface elevations measured in August 1999 and September 2000 are presented for seven control riffles, which include TM1, R10, R12, R20, R27, R59, and R76. The elevations for pre-project conditions for riffles R5, R12A, R13, R14A, R15, R16, R19, R19A, and R57 were estimated by superimposing the locations of new transects established between 24 August and 29 September 1999 onto the pre-project contour maps in Appendix 3 of the Task 5 report (CMC 2001b) and then by interpolating between the contour lines and using nearby measured values. The elevations shown in these graphs are comparable to those in the contour maps in Appendix 3.



TMA
Relative Elevation (ft)
1
0
-1
-2
-3
-4
-20
0
20
40
60
80
100
120
140
375 cfs
Pre-Project
Sep 1999
Sep 2000

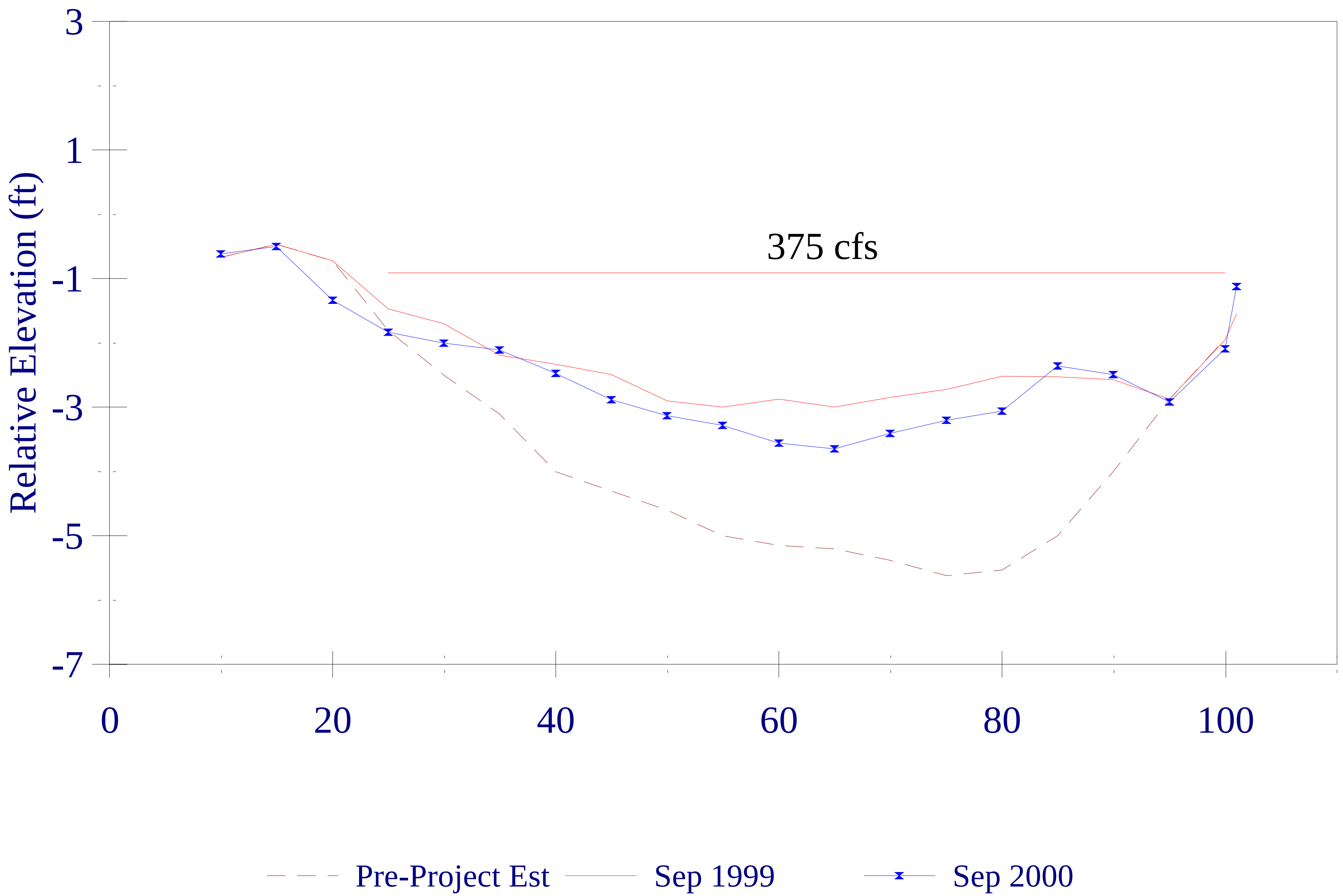


TM1
Relative Elevation (ft)
8
6
4
2
0
-2
-4
-6
-10
10
30
50
70
90
110
130
150
1,800 cfs
375 cfs
Aug 1999
Sep 2000

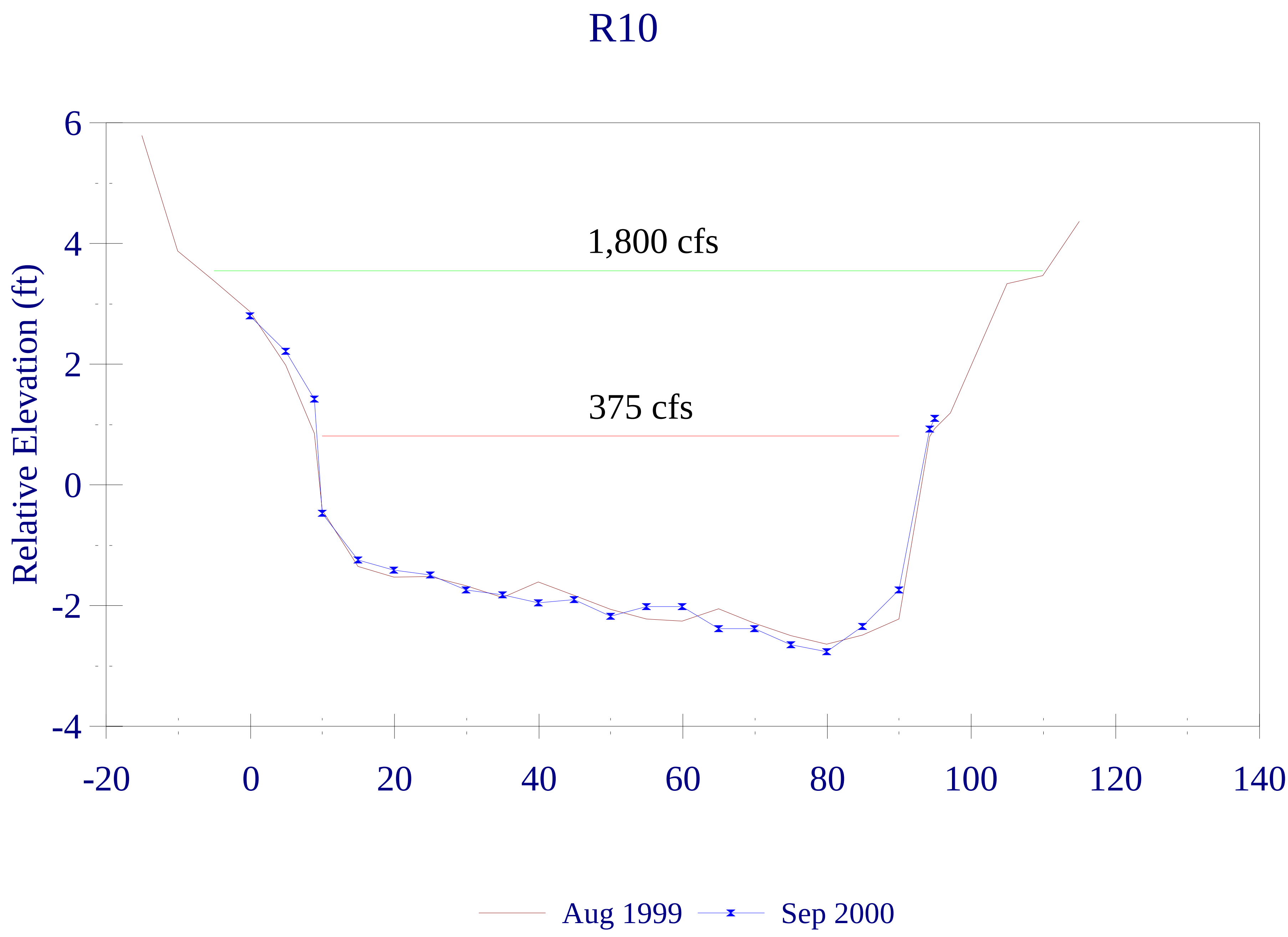


R1
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-10
-10
10
30
50
70
90
110
130
375 cfs
Pre-Project
Sep 1999
Sep 2000

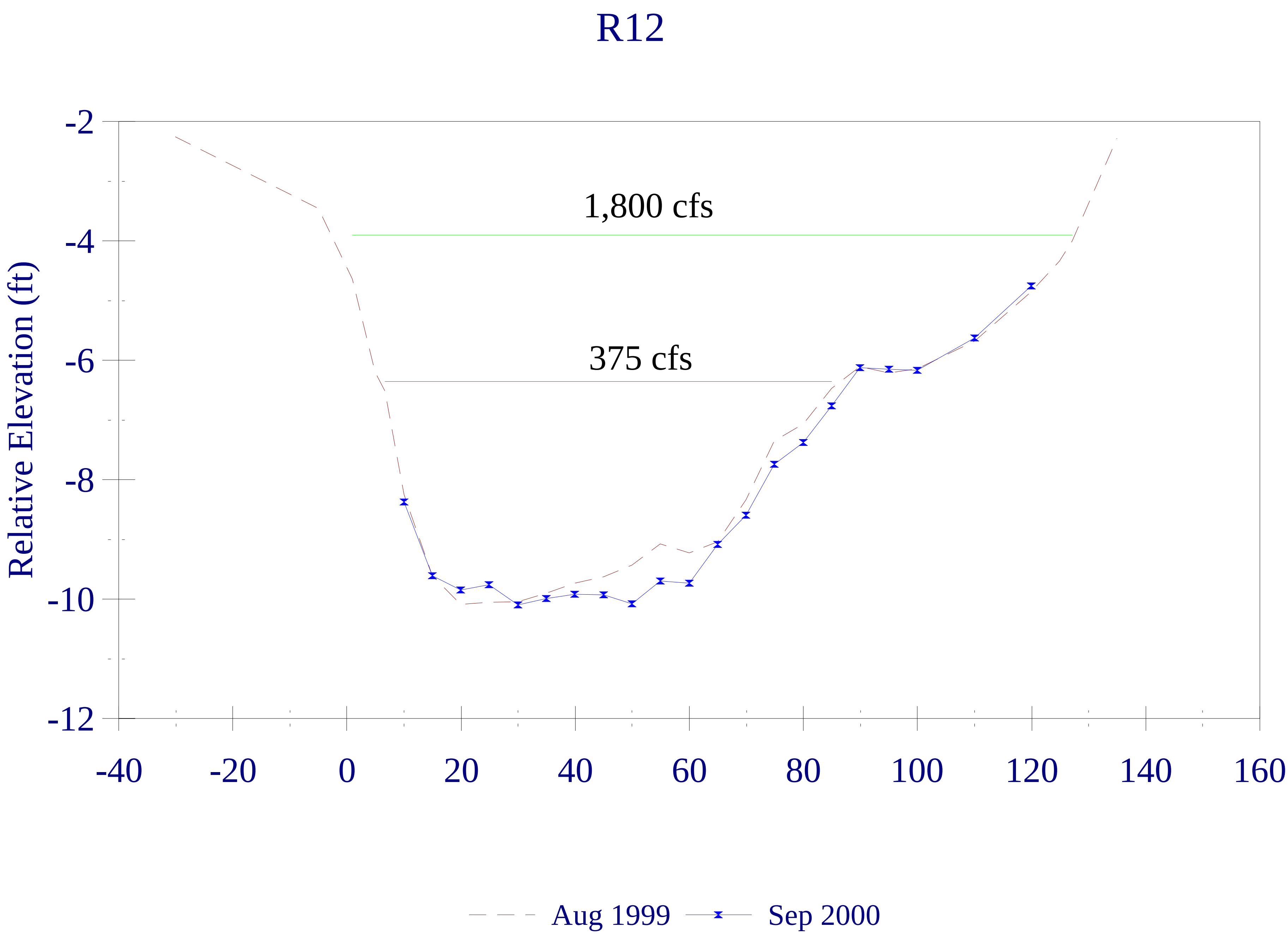
R5



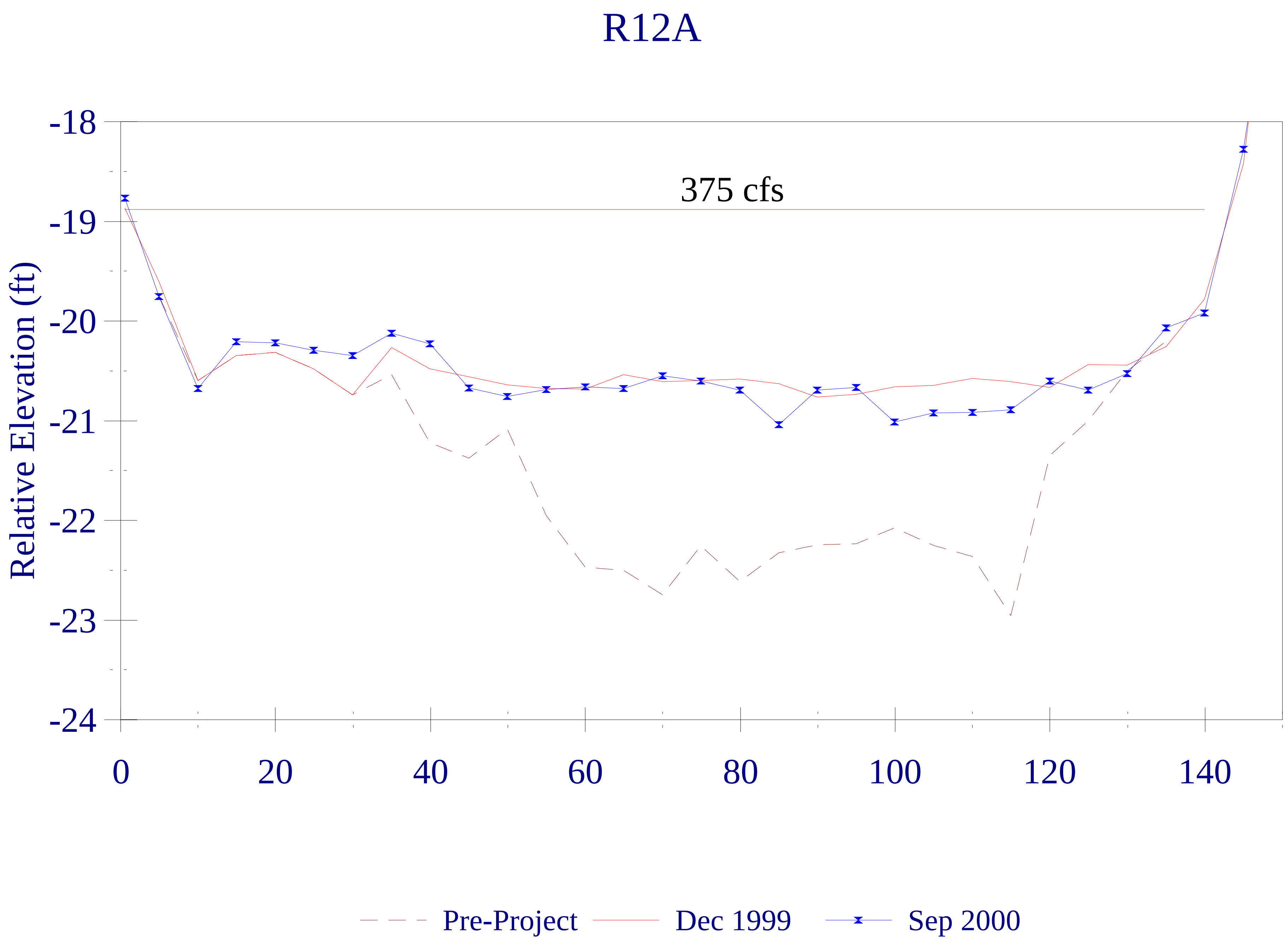
3
1
-1
-3
-5
-7
Relative Elevation (ft)
375 cfs
0
20
40
60
80
100
Pre-Project Est
Sep 1999
Sep 2000



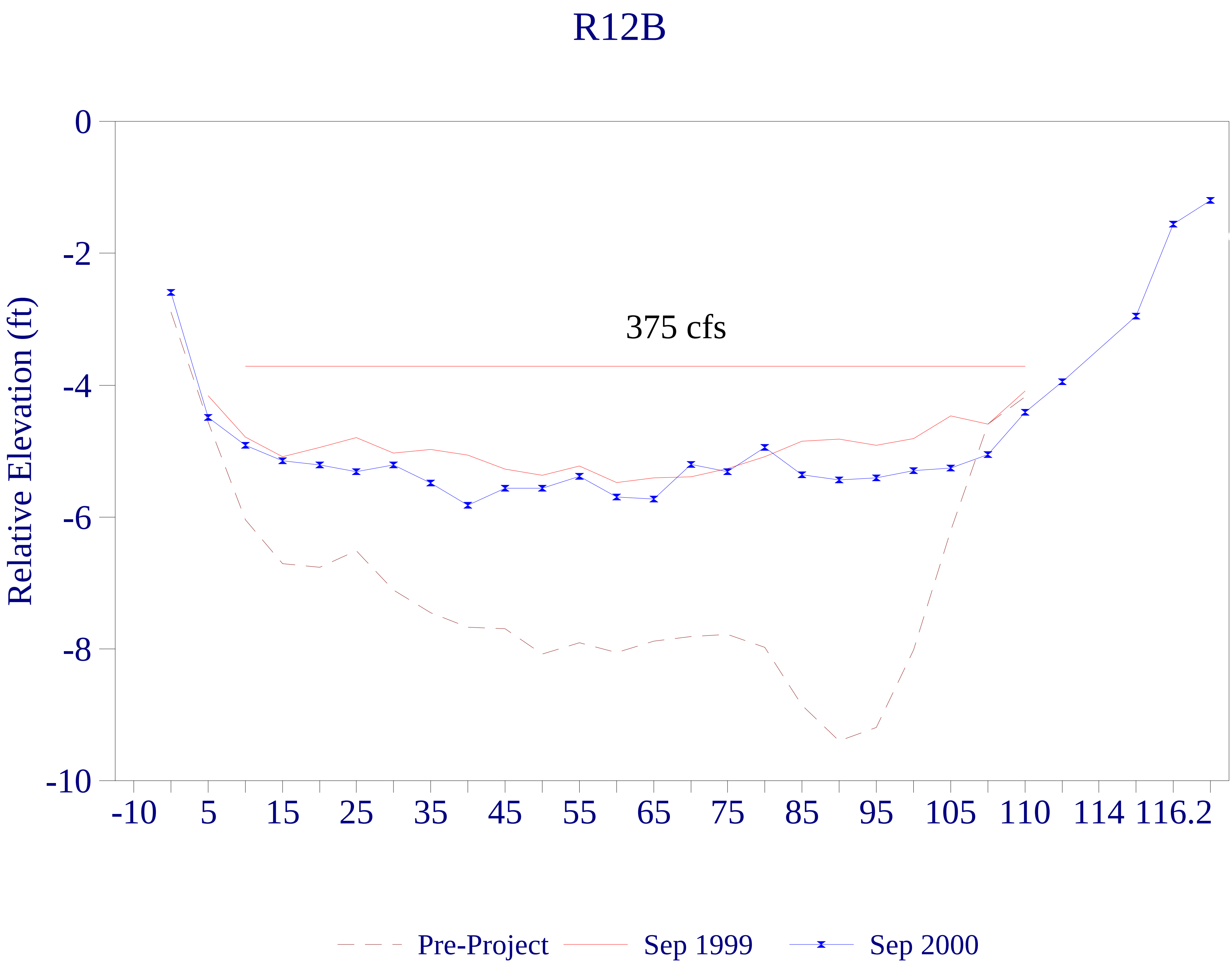
R10
6
4
2
0
-2
-4
Relative Elevation (ft)
1,800 cfs
375 cfs
-20
0
20
40
60
80
100
120
140
Aug 1999
Sep 2000

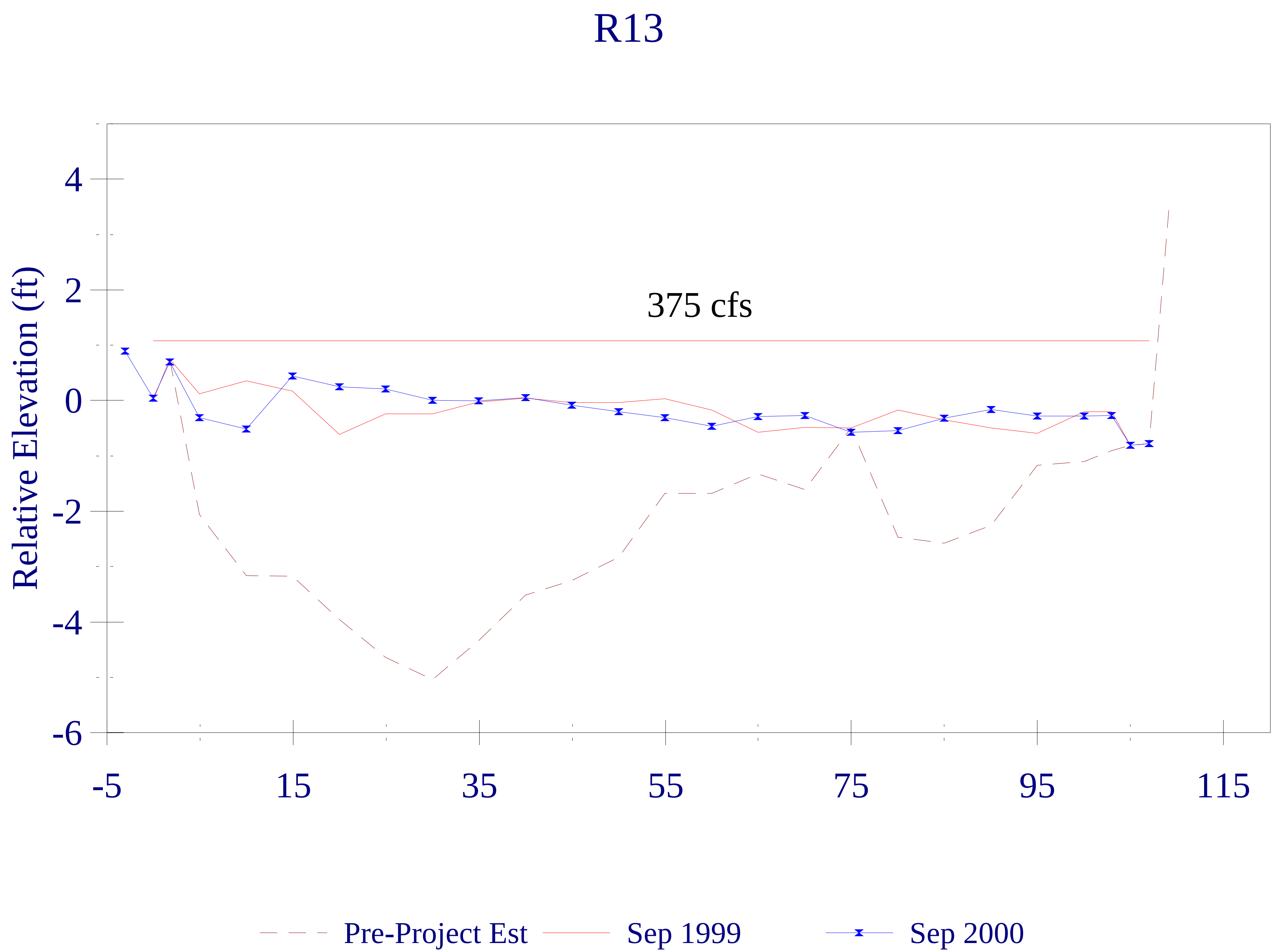


R12
1,800 cfs
375 cfs
Relative Elevation (ft)
-2
-4
-6
-8
-10
-12
-40
-20
0
20
40
60
80
100
120
140
160
Aug 1999
Sep 2000

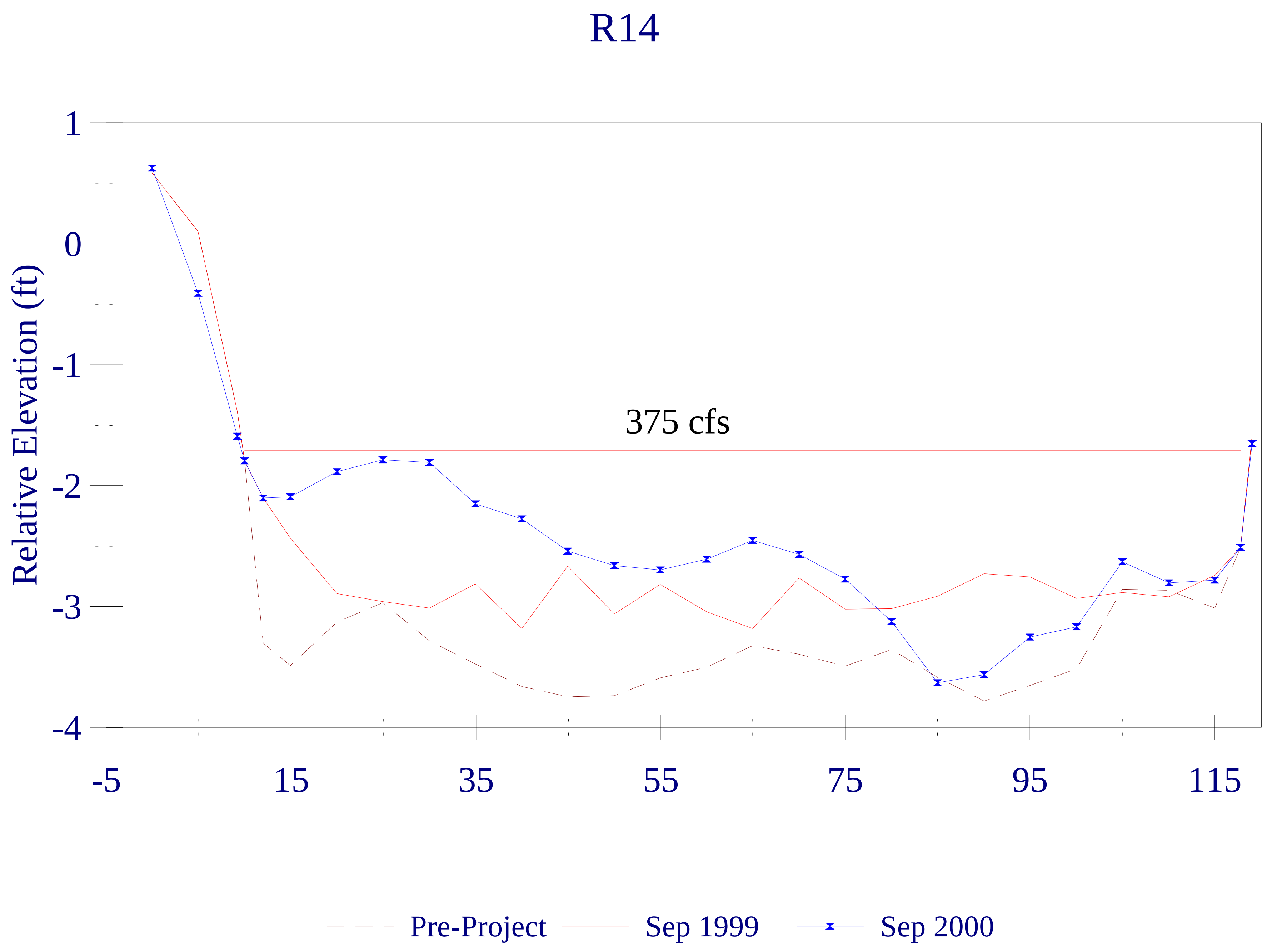


R12A
375 cfs
Relative Elevation (ft)
-18
-19
-20
-21
-22
-23
-24
0
20
40
60
80
100
120
140
Pre-Project
Dec 1999
Sep 2000

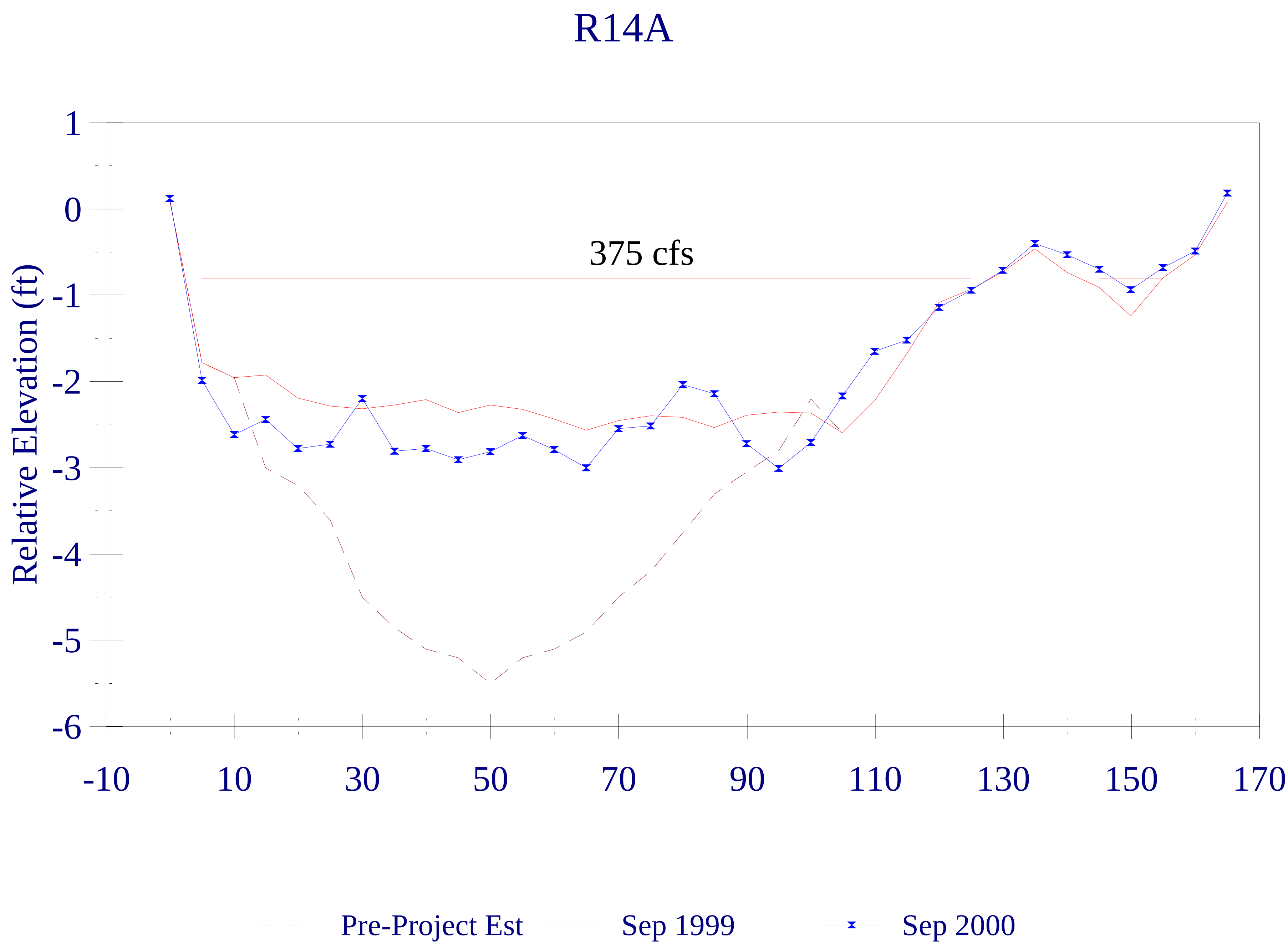

R12B
Relative Elevation (ft)
0
-2
-4
-6
-8
-10
375 cfs
-10
5
15
25
35
45
55
65
75
85
95
105
110
114
116.2
Pre-Project
Sep 1999
Sep 2000



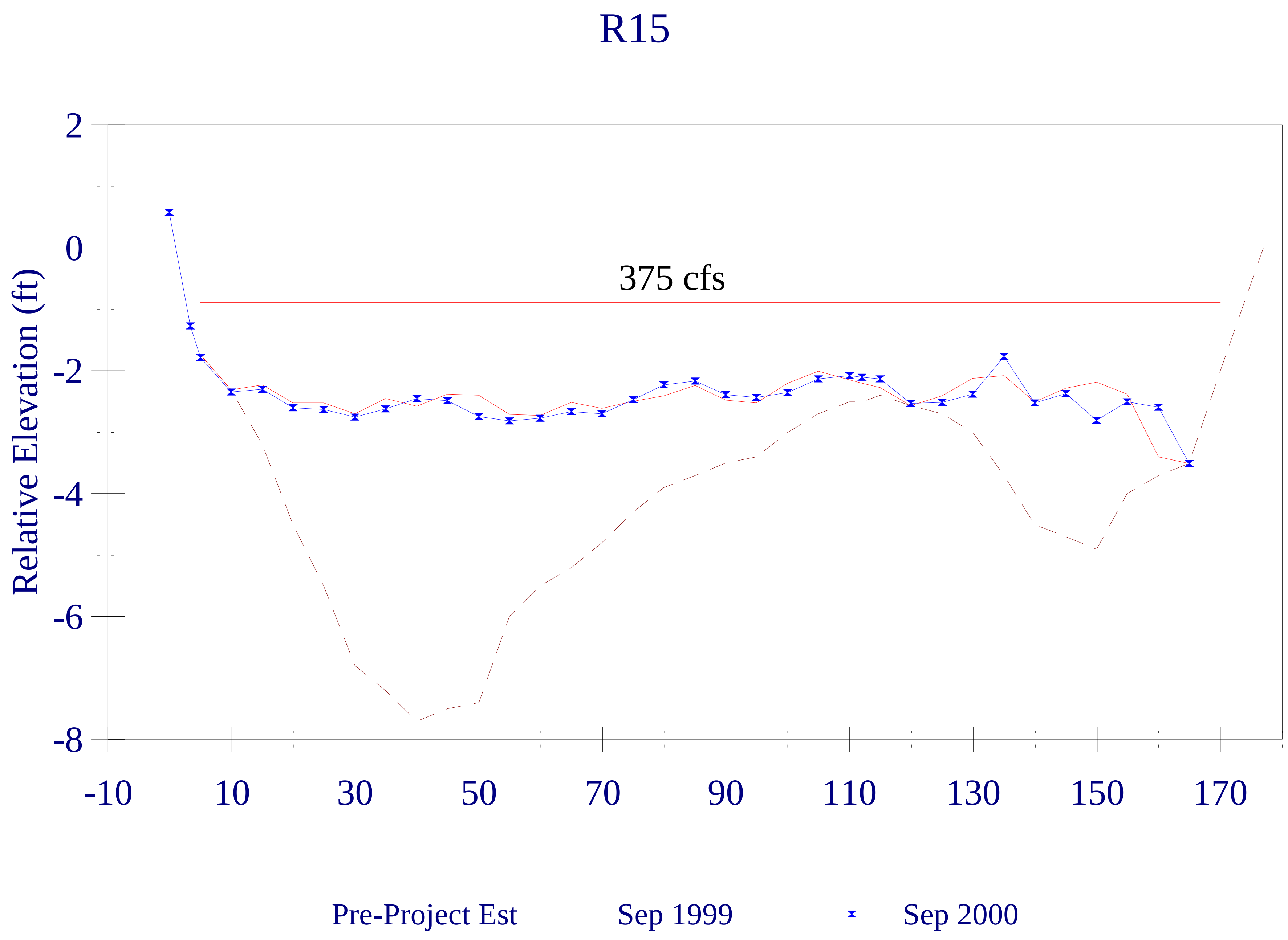
R13
Relative Elevation (ft)
375 cfs
4
2
0
-2
-4
-6
-5
15
35
55
75
95
115
Pre-Project Est
Sep 1999
Sep 2000



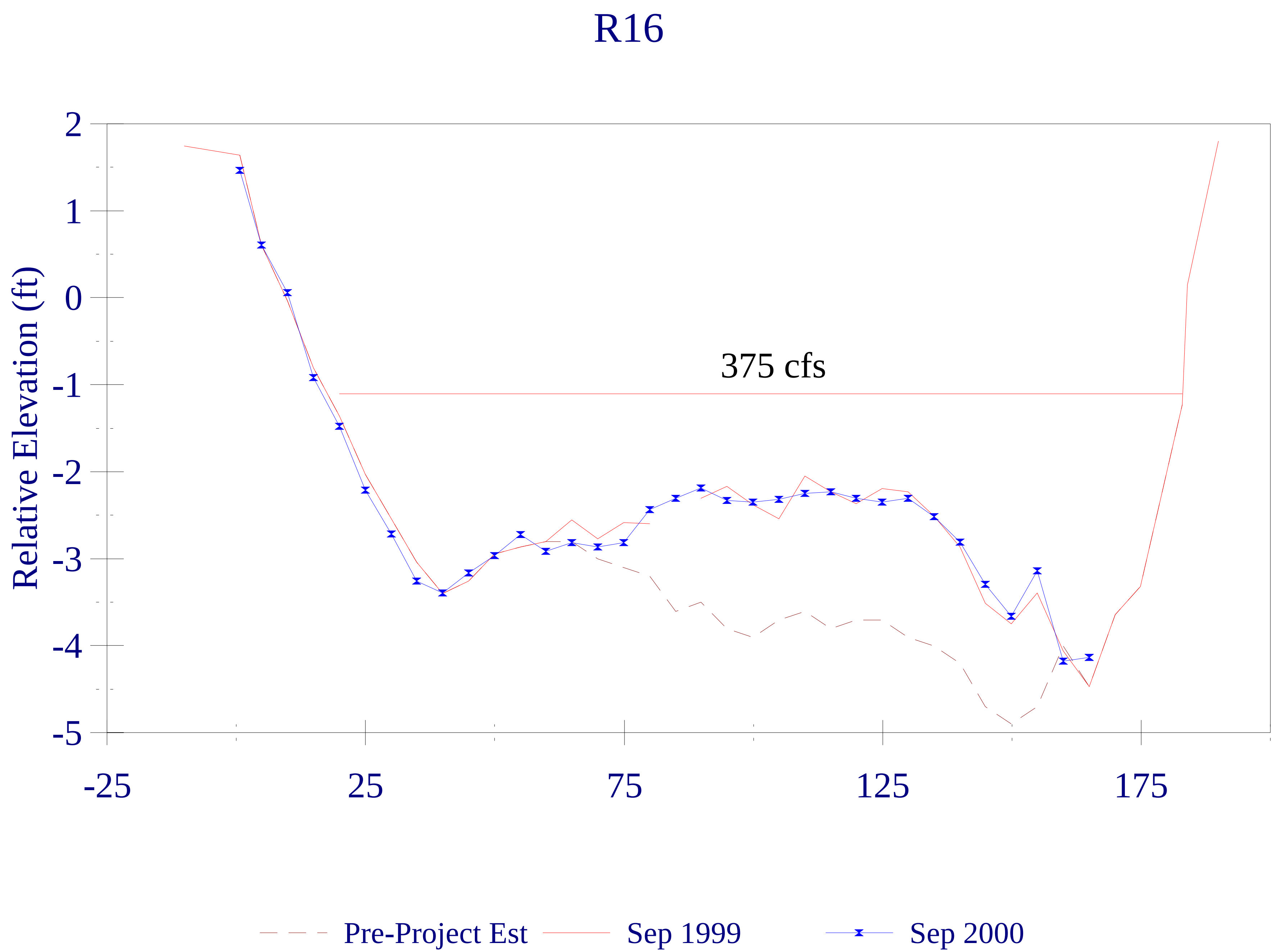
R14
Relative Elevation (ft)
1
0
-1
-2
-3
-4
-5
15
35
55
75
95
115
375 cfs
Pre-Project
Sep 1999
Sep 2000



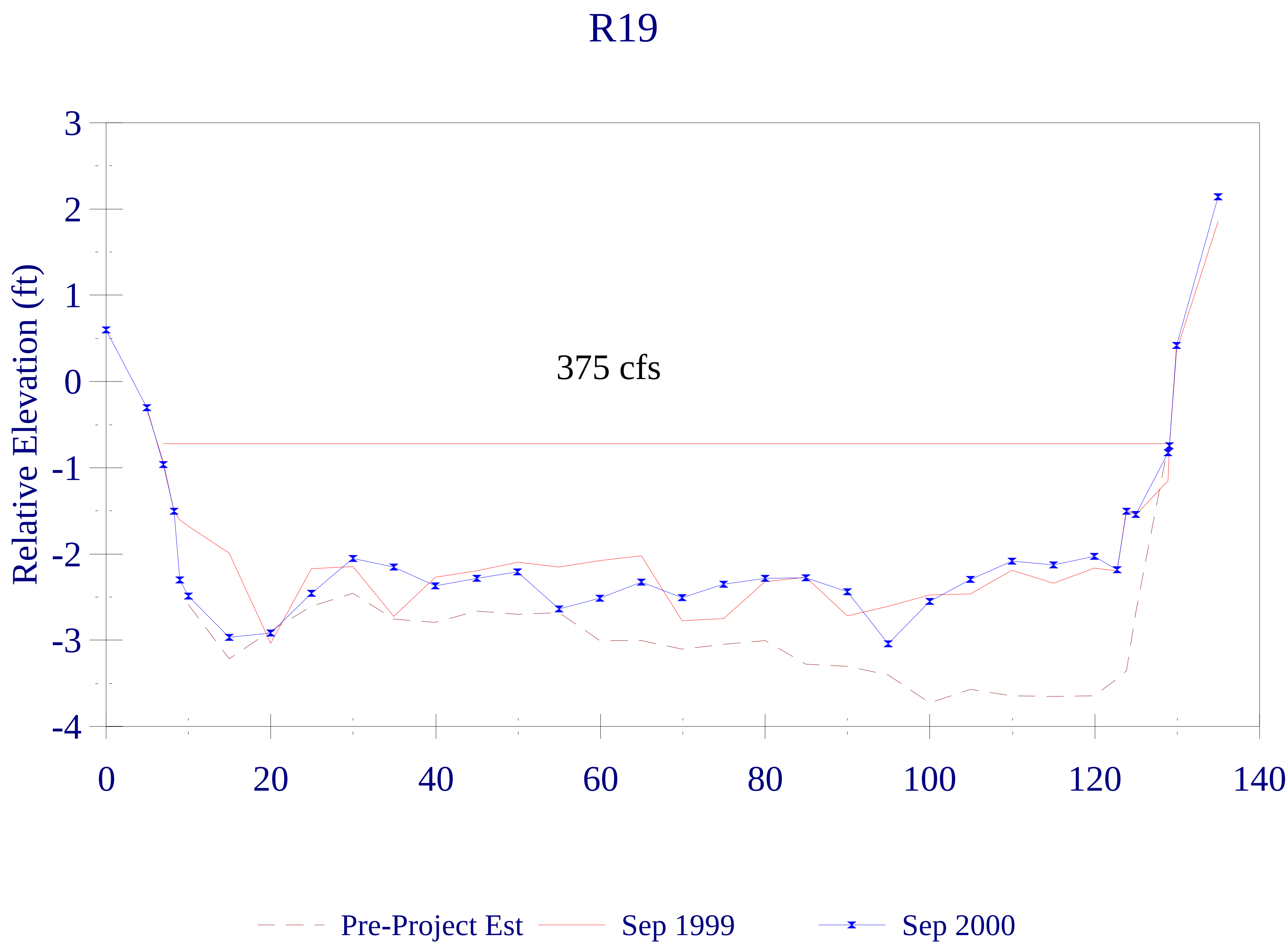
R14A
Relative Elevation (ft)
1
0
-1
-2
-3
-4
-5
-6
-10
10
30
50
70
90
110
130
150
170
375 cfs
Pre-Project Est
Sep 1999
Sep 2000

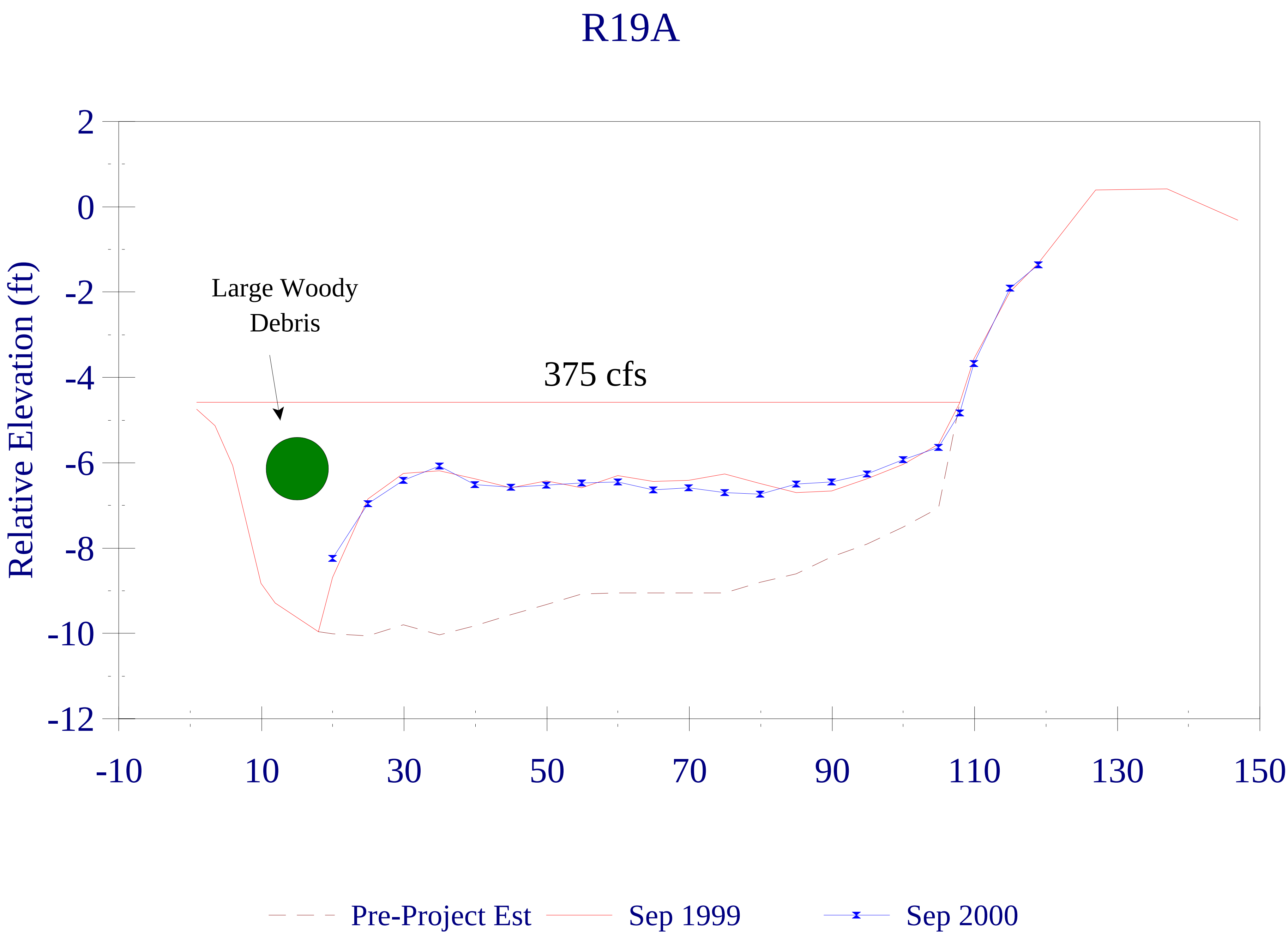


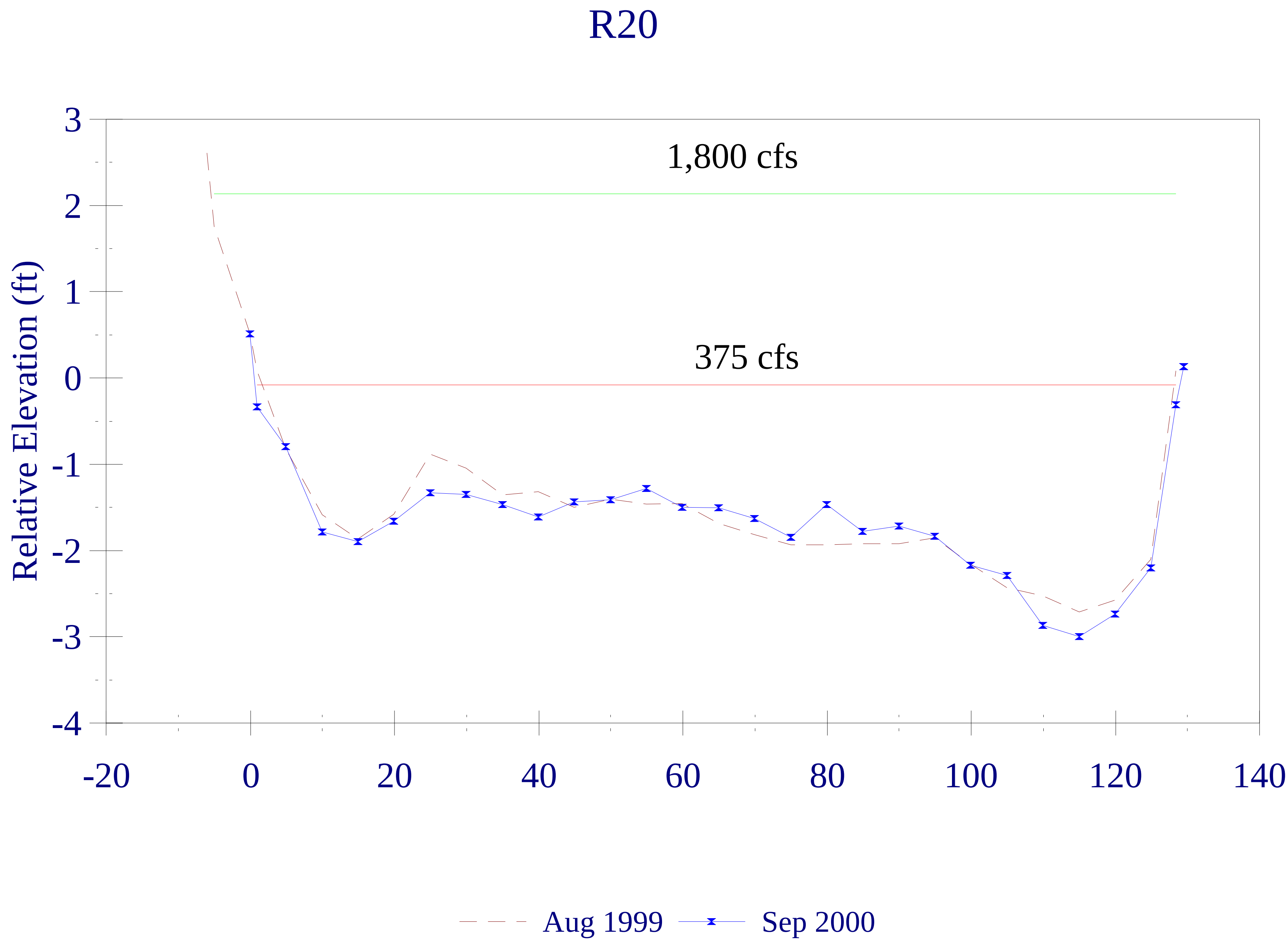
R15
375 cfs
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-10
10
30
50
70
90
110
130
150
170
Pre-Project Est
Sep 1999
Sep 2000



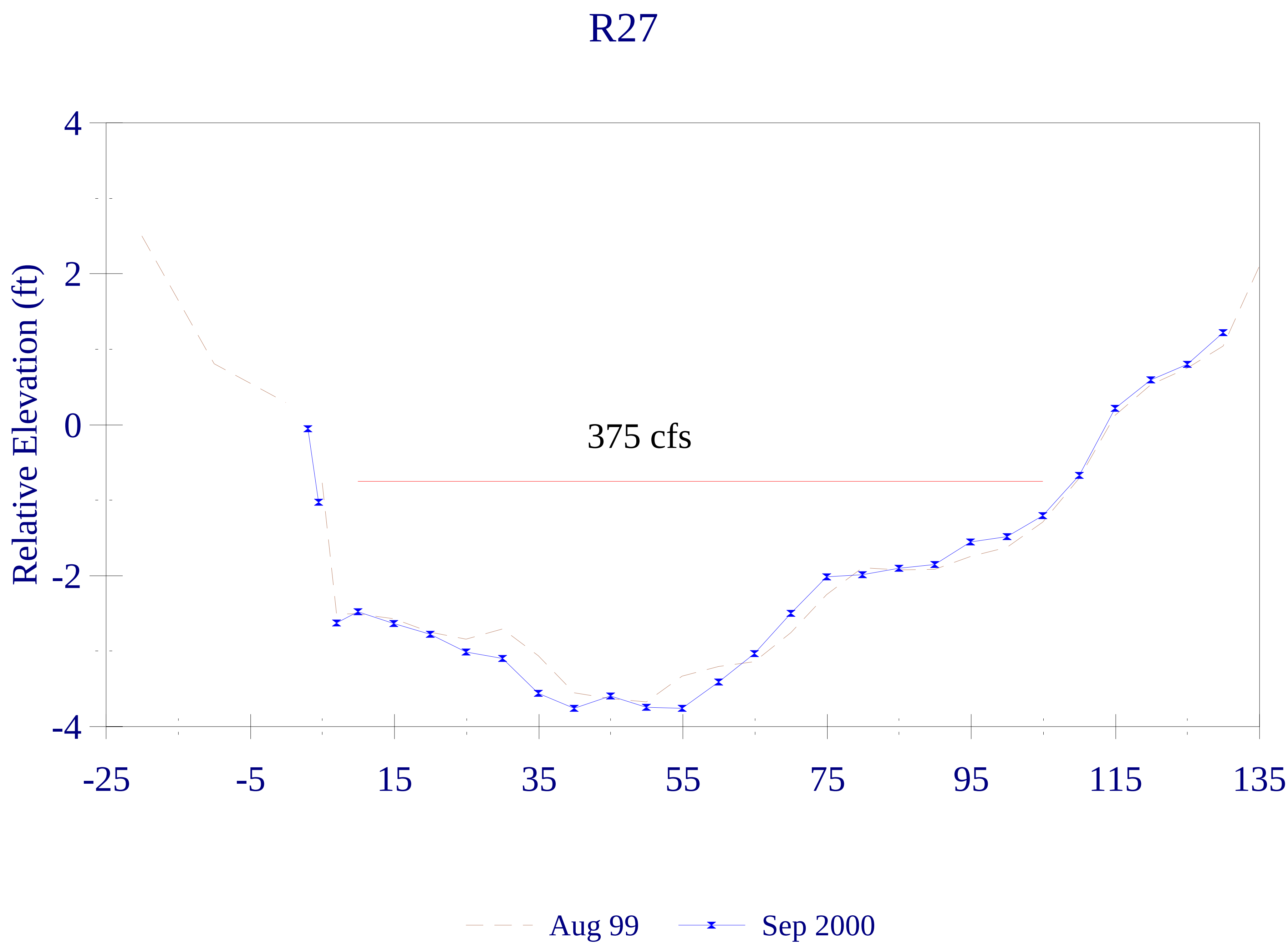
R16
375 cfs
Relative Elevation (ft)
2
1
0
-1
-2
-3
-4
-5
-25
25
75
125
175
Pre-Project Est
Sep 1999
Sep 2000


R19
Relative Elevation (ft)
3
2
1
0
-1
-2
-3
-4
0
20
40
60
80
100
120
140
375 cfs
Pre-Project Est
Sep 1999
Sep 2000


R19A
Relative Elevation (ft)
2
0
-2
-4
-6
-8
-10
-12
-10
10
30
50
70
90
110
130
150
Large Woody
Debris
375 cfs
Pre-Project Est
Sep 1999
Sep 2000

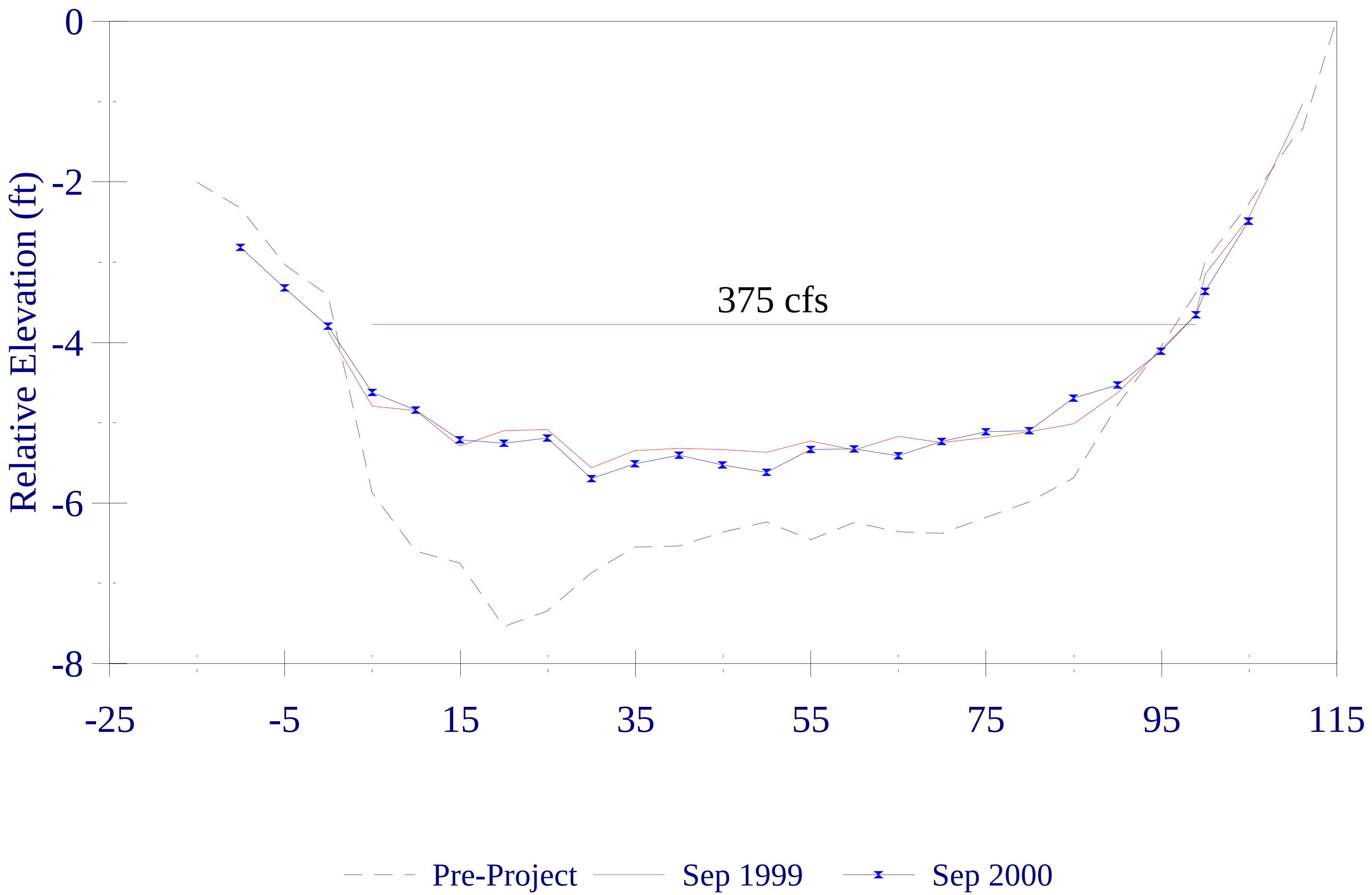


R20
1,800 cfs
375 cfs
Relative Elevation (ft)
3
2
1
0
-1
-2
-3
-4
-20
0
20
40
60
80
100
120
140
Aug 1999
Sep 2000

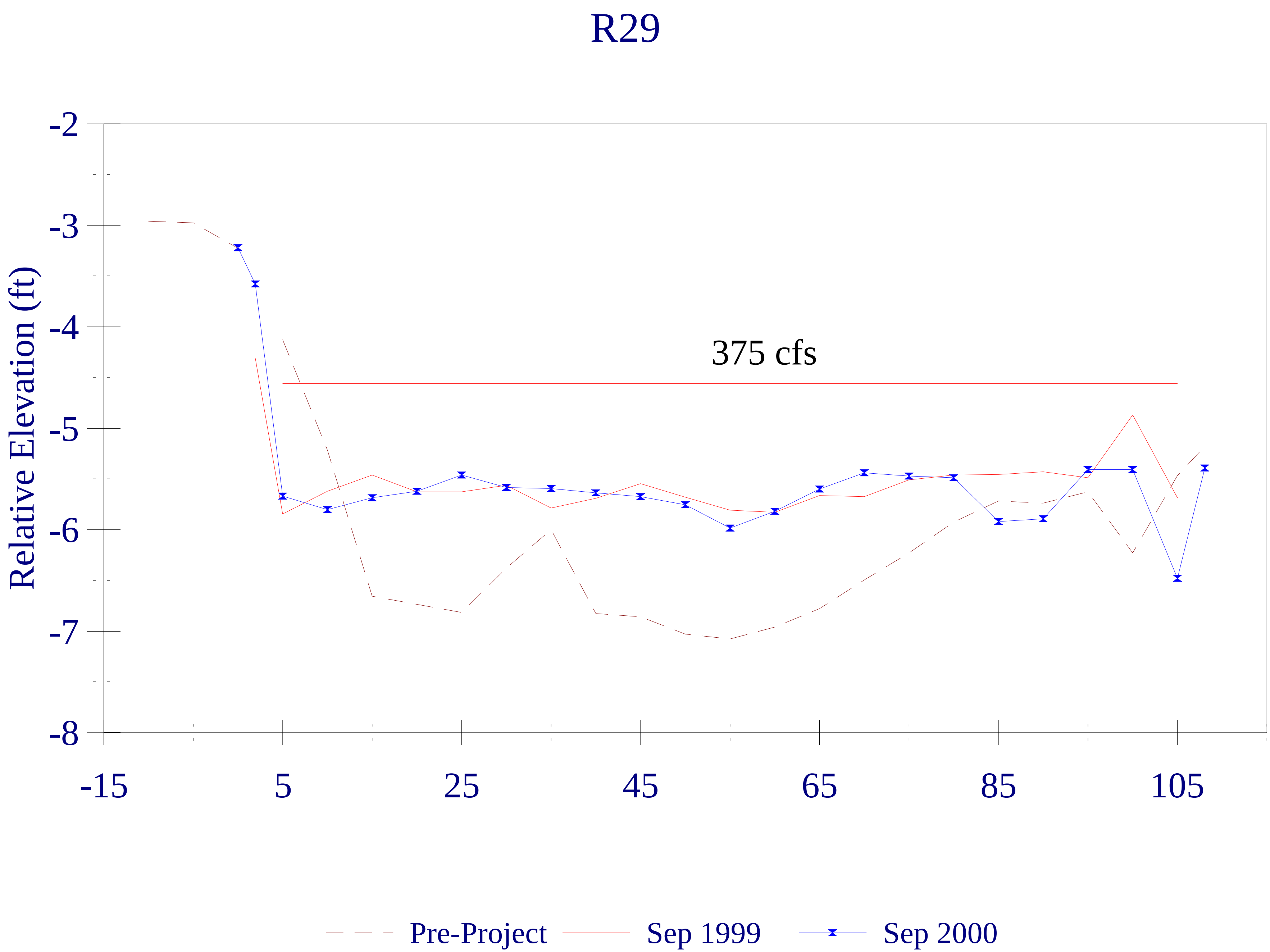


R27
Relative Elevation (ft)
4
2
0
-2
-4
375 cfs
-25
-5
15
35
55
75
95
115
135
Aug 99
Sep 2000

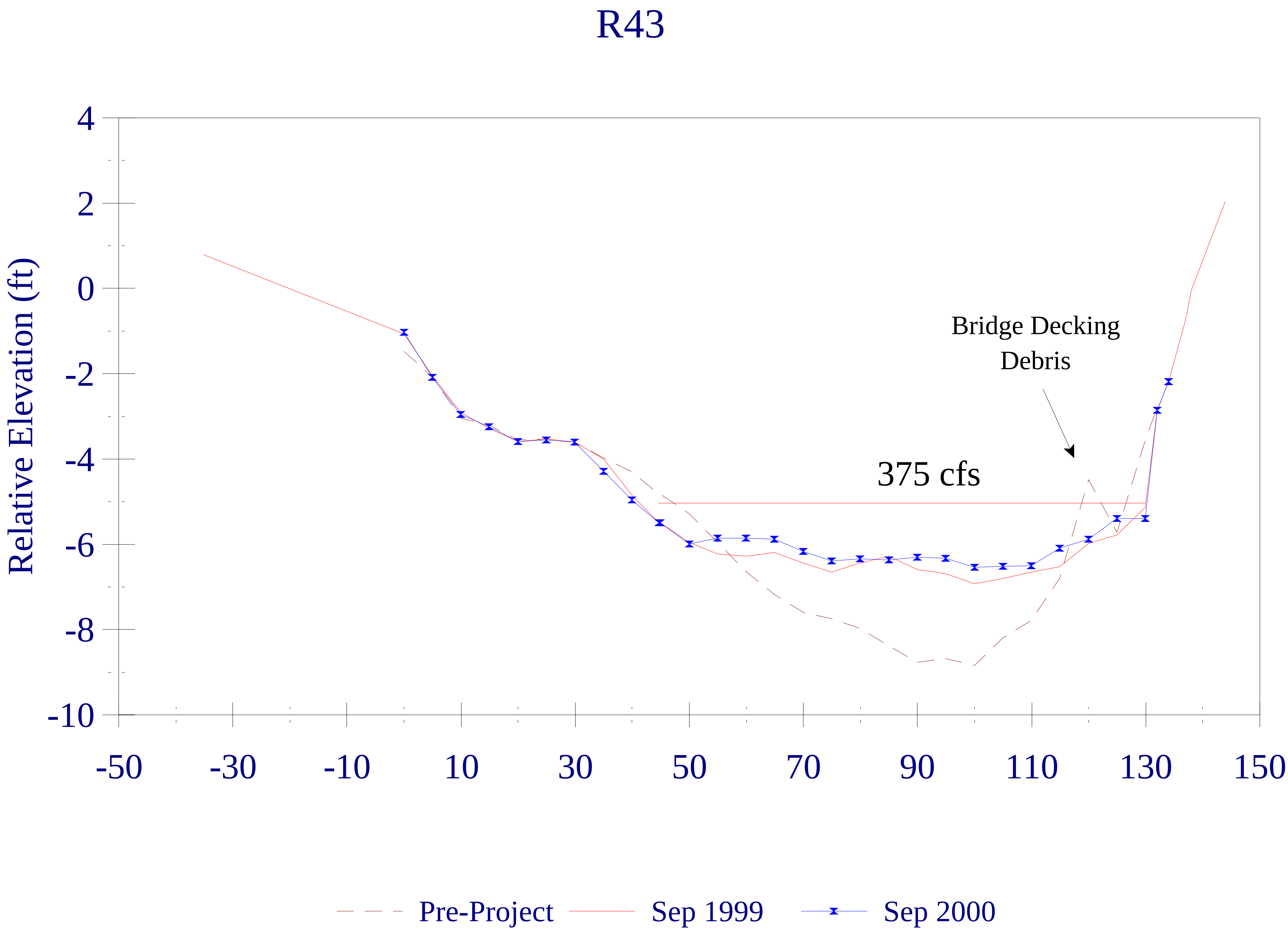
R28A



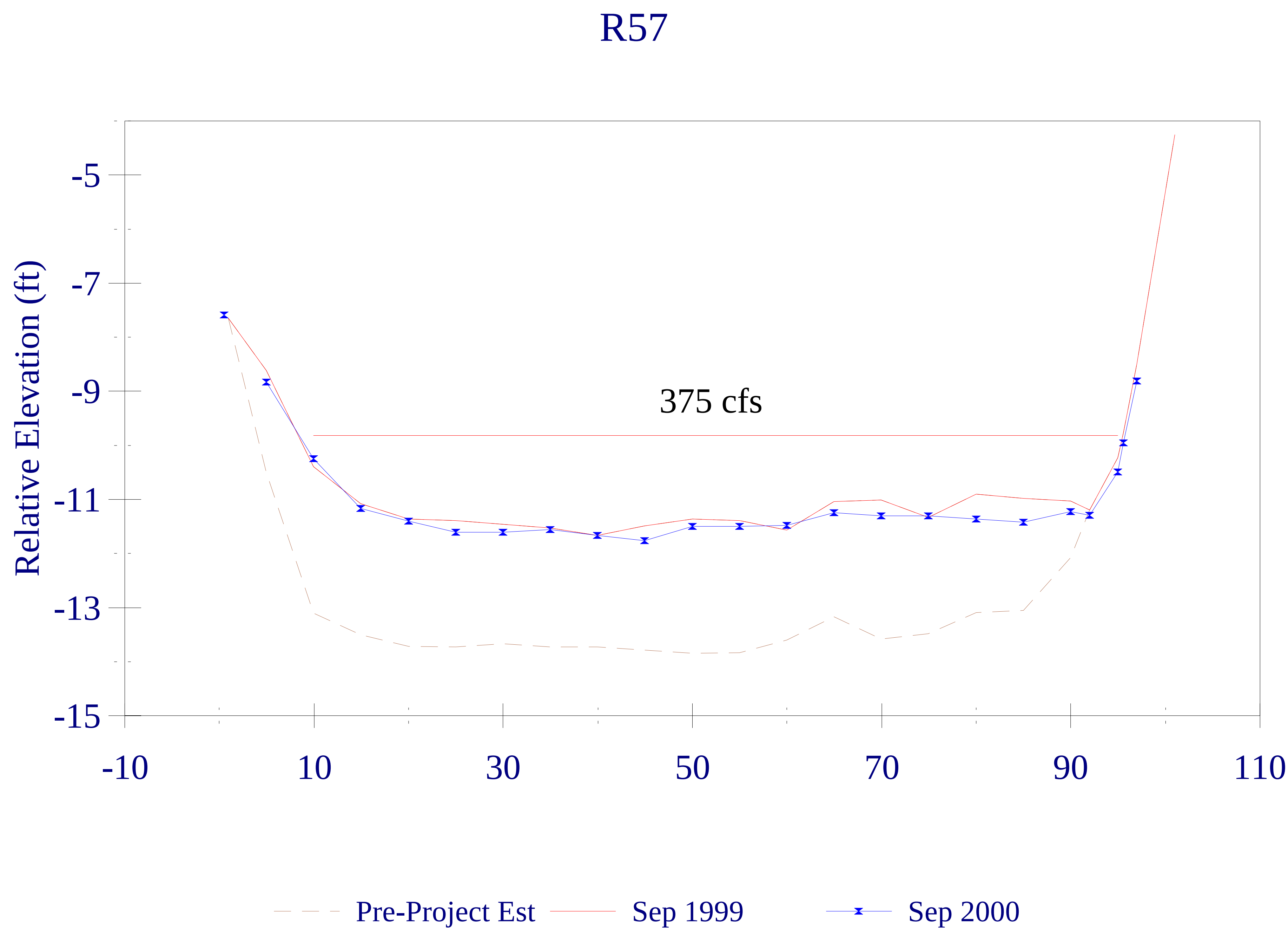
0
-2
-4
-6
-8
Relative Elevation (ft)
375 cfs
-25
-5
15
35
55
75
95
115
Pre-Project
Sep 1999
Sep 2000

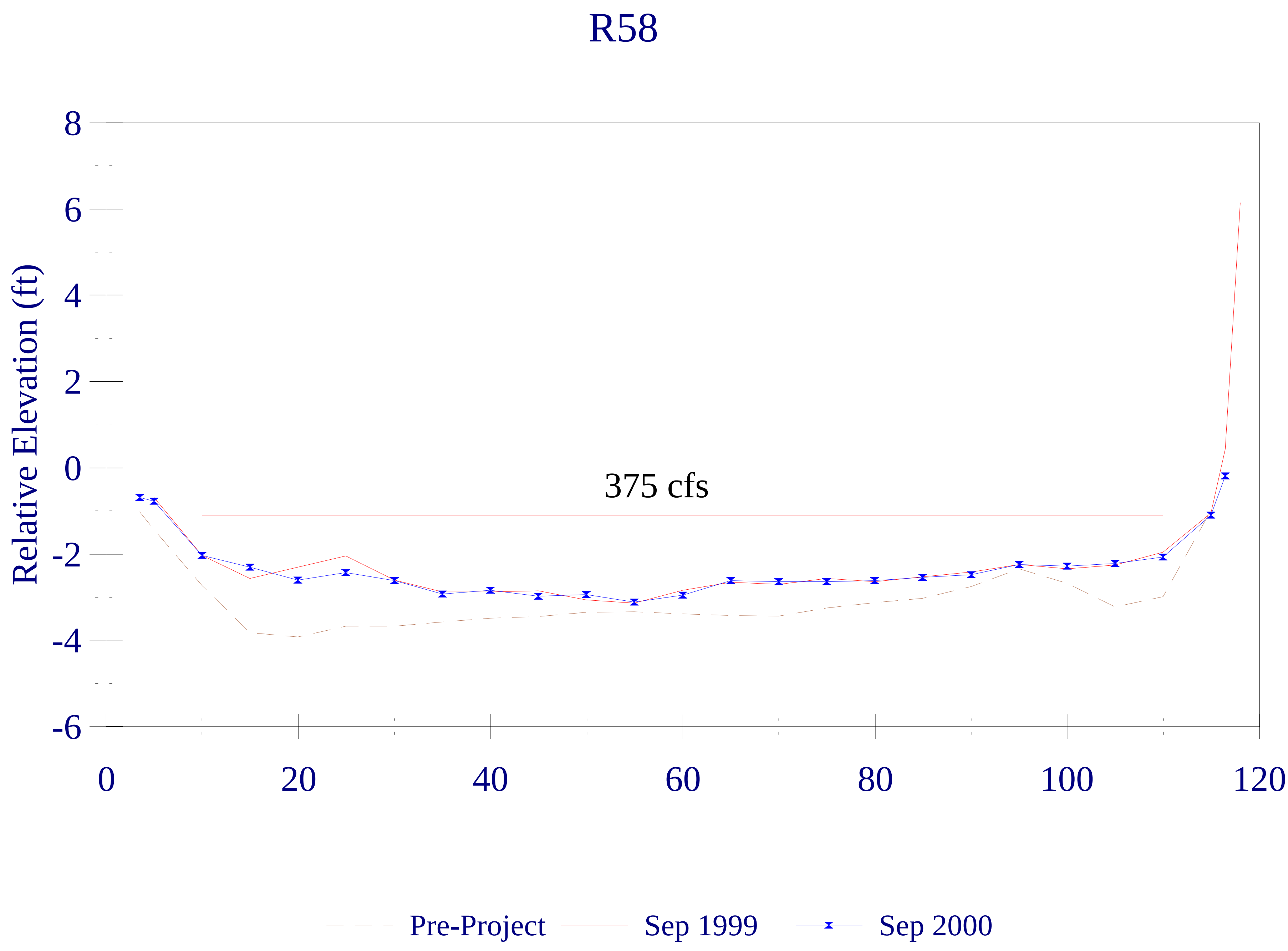


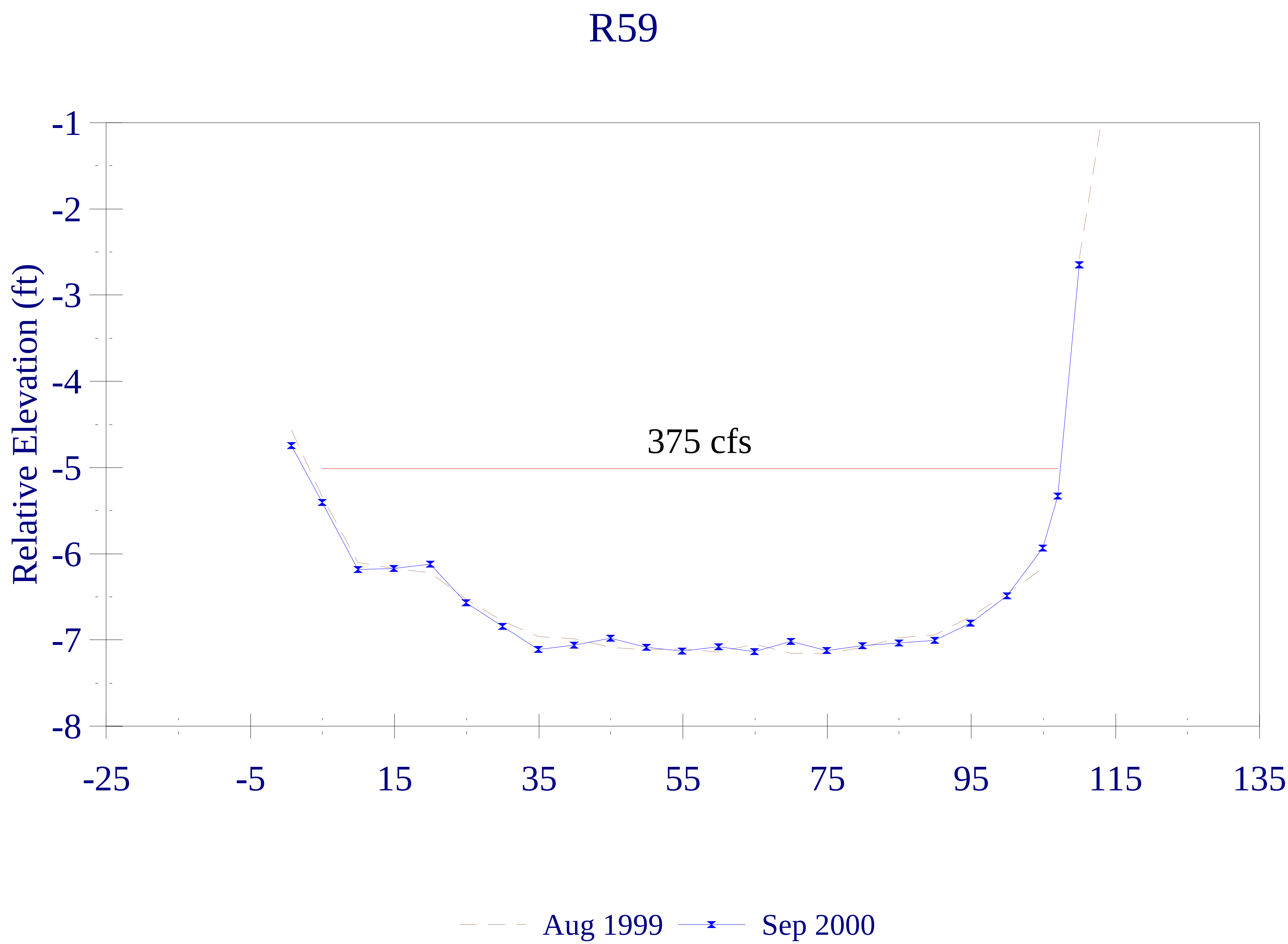
R29
Relative Elevation (ft)
375 cfs
-2
-3
-4
-5
-6
-7
-8
-15
5
25
45
65
85
105
Pre-Project
Sep 1999
Sep 2000

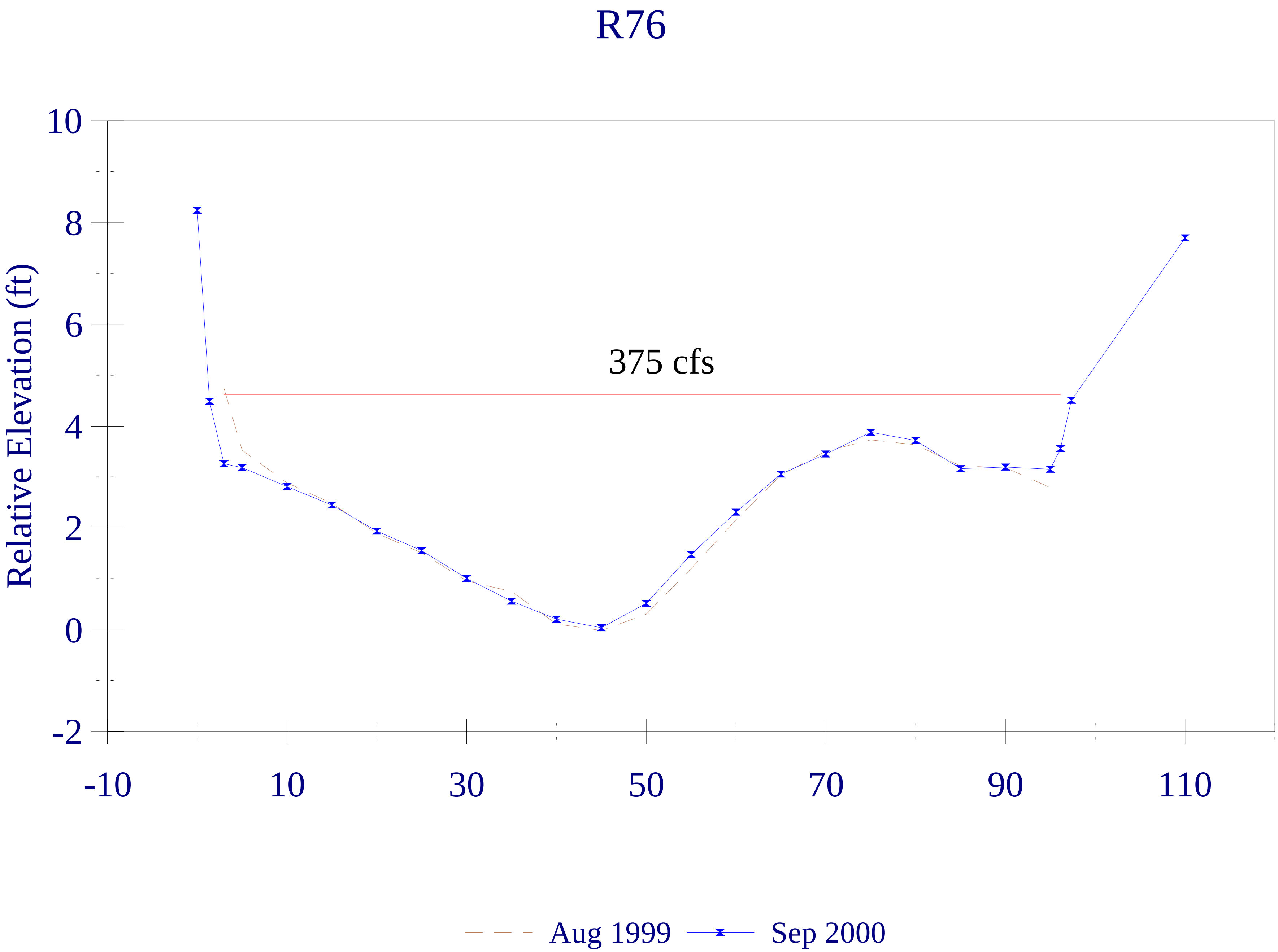


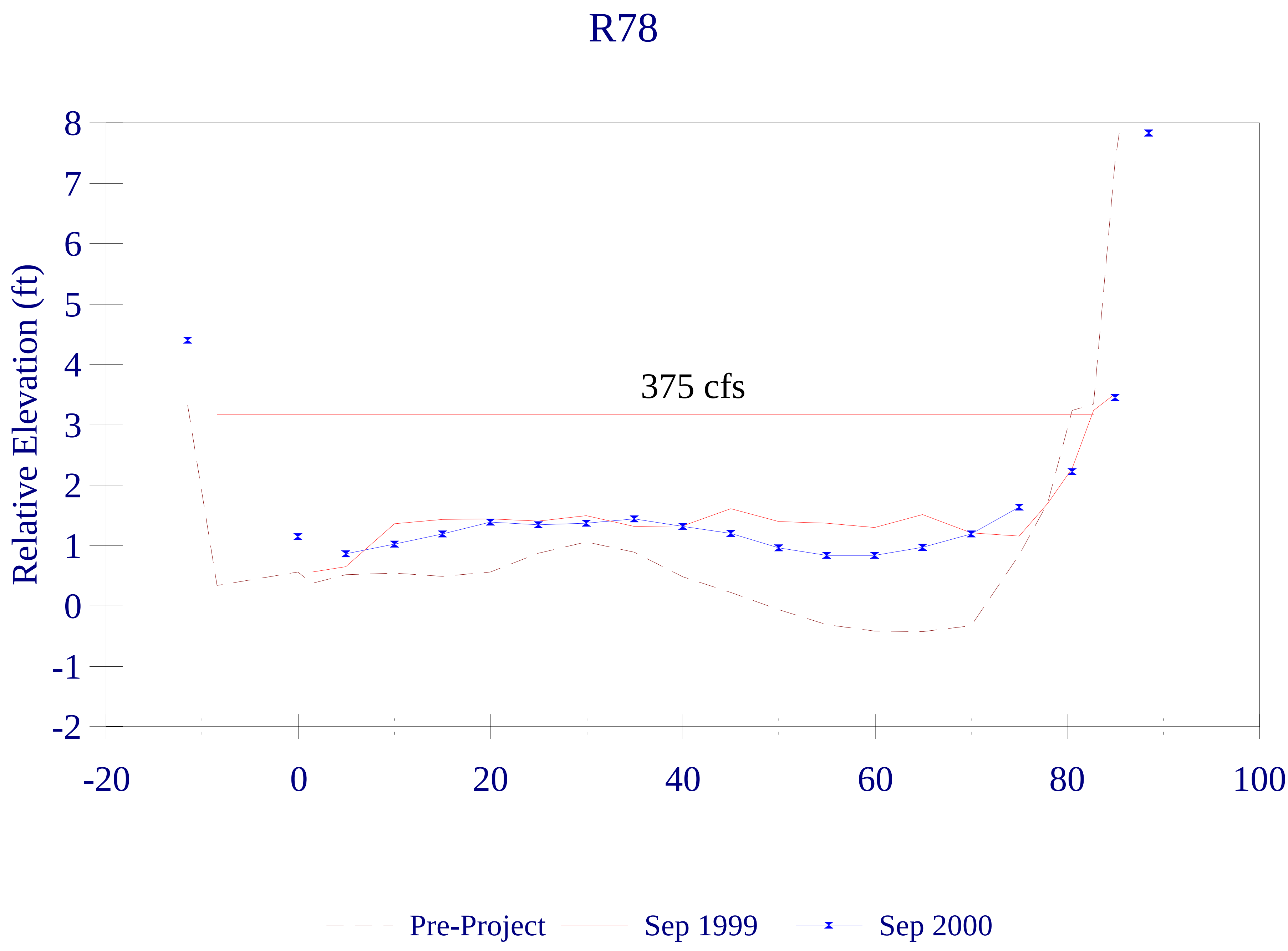
R43
Relative Elevation (ft)
4
2
0
-2
-4
-6
-8
-10
-50
-30
-10
10
30
50
70
90
110
130
150
Bridge Decking
Debris
375 cfs
Pre-Project
Sep 1999
Sep 2000


R57
Relative Elevation (ft)
-5
-7
-9
-11
-13
-15
-10
10
30
50
70
90
110
375 cfs
Pre-Project Est
Sep 1999
Sep 2000


R58
Relative Elevation (ft)
8
6
4
2
0
-2
-4
-6
0
20
40
60
80
100
120
375 cfs
Pre-Project
Sep 1999
Sep 2000


R59
Relative Elevation (ft)
-1
-2
-3
-4
-5
-6
-7
-8
-25
-5
15
35
55
75
95
115
135
375 cfs
Aug 1999
Sep 2000


R76
Relative Elevation (ft)
10
8
6
4
2
0
-2
-10
10
30
50
70
90
110
375 cfs
Aug 1999
Sep 2000

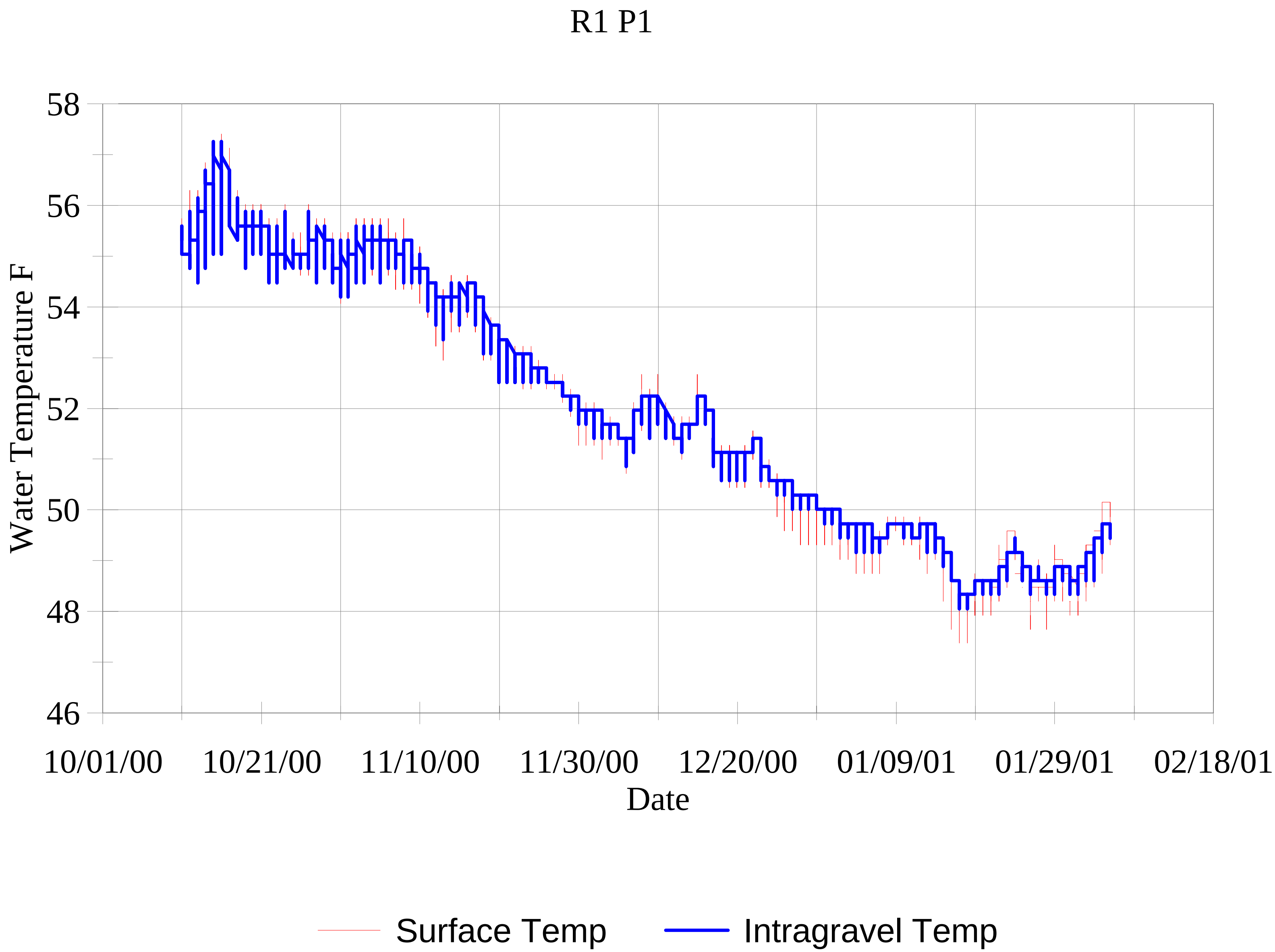

R78
Relative Elevation (ft)
8
7
6
5
4
3
2
1
0
-1
-2
-20
0
20
40
60
80
100
375 cfs
Pre-Project
Sep 1999
Sep 2000

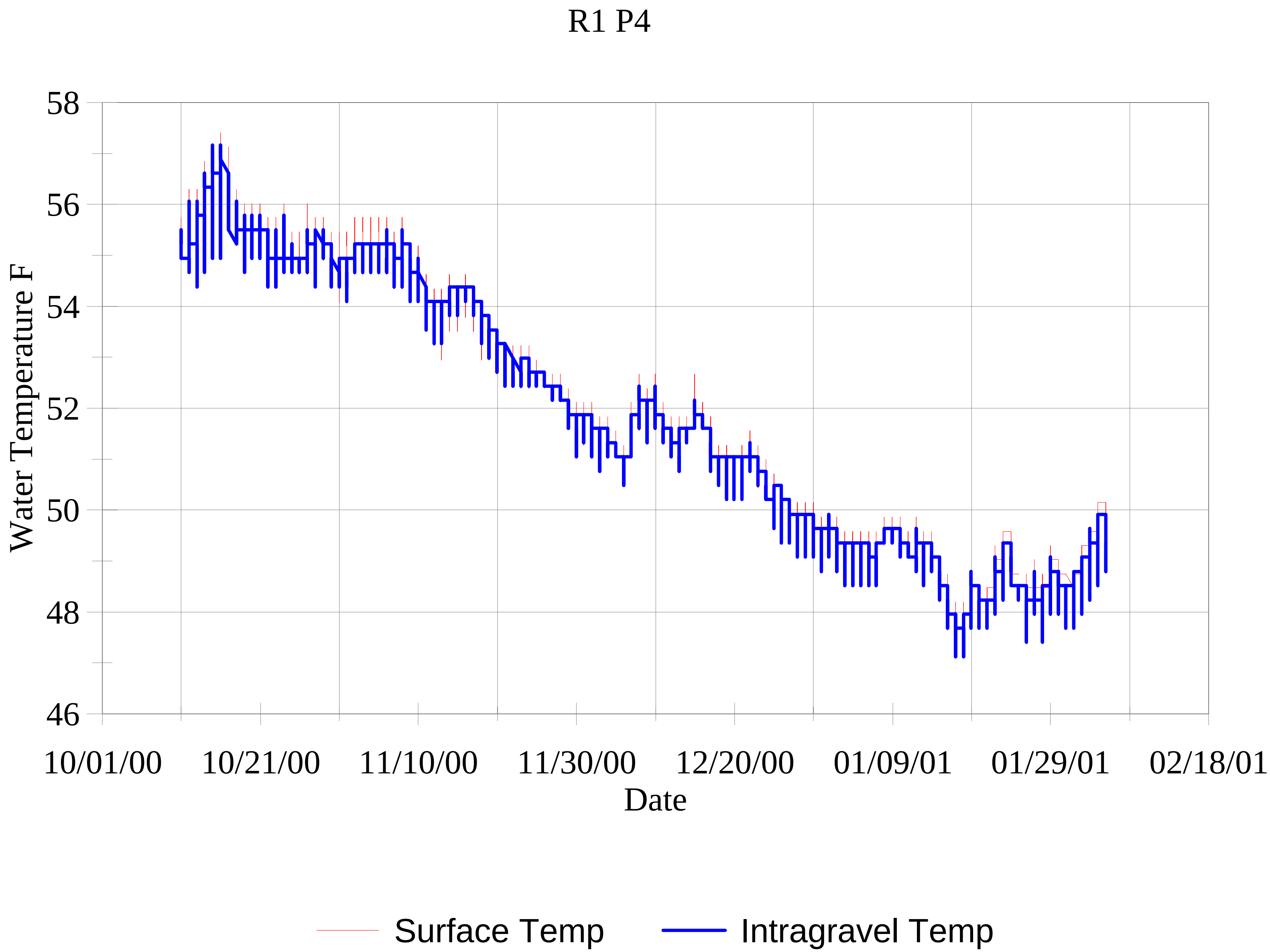
APPENDIX 5

Intragravel and Surface Water Temperatures from October 2000 to February 2001.

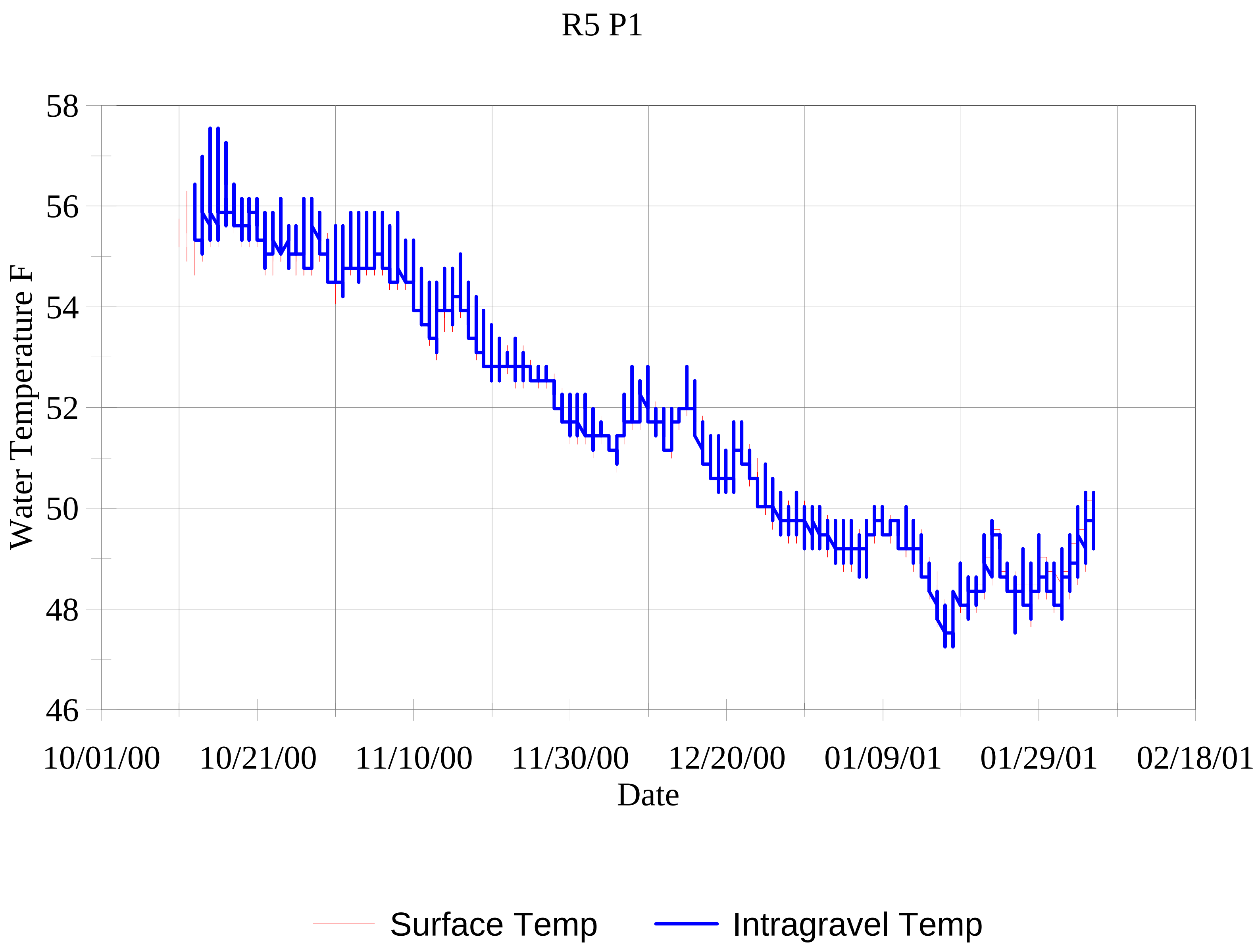
Intragravel water temperatures were measured at 30-minute intervals with *Onset Tidbit* thermographs buried with piezometers in artificial redds at 22 study riffles in the Stanislaus river between Goodwin Dam and Oakdale. Thermographs also monitored surface flows near the river margin near riffles R5, R10, R14, R28A, R59, and R76. Comparisons between surface and intragravel measurements at riffles where no surface thermograph was installed utilized the surface data collected at the closest riffle.

For 57 of the 72 buried thermographs that were recovered, the magnitude and fluctuation in intragravel water temperatures were nearly identical to those of the surface flow. As examples of these sites, thermograph data are presented in this appendix for the following piezometers: R1 P4, R5 P1, R14A P1, R20 P1, R29 P1, R57 P2, R58 P4, R76 P1, and R78 P1. The data from the 15 buried thermographs that deviated in either magnitude or fluctuation from the surface temperatures are also presented in this appendix.

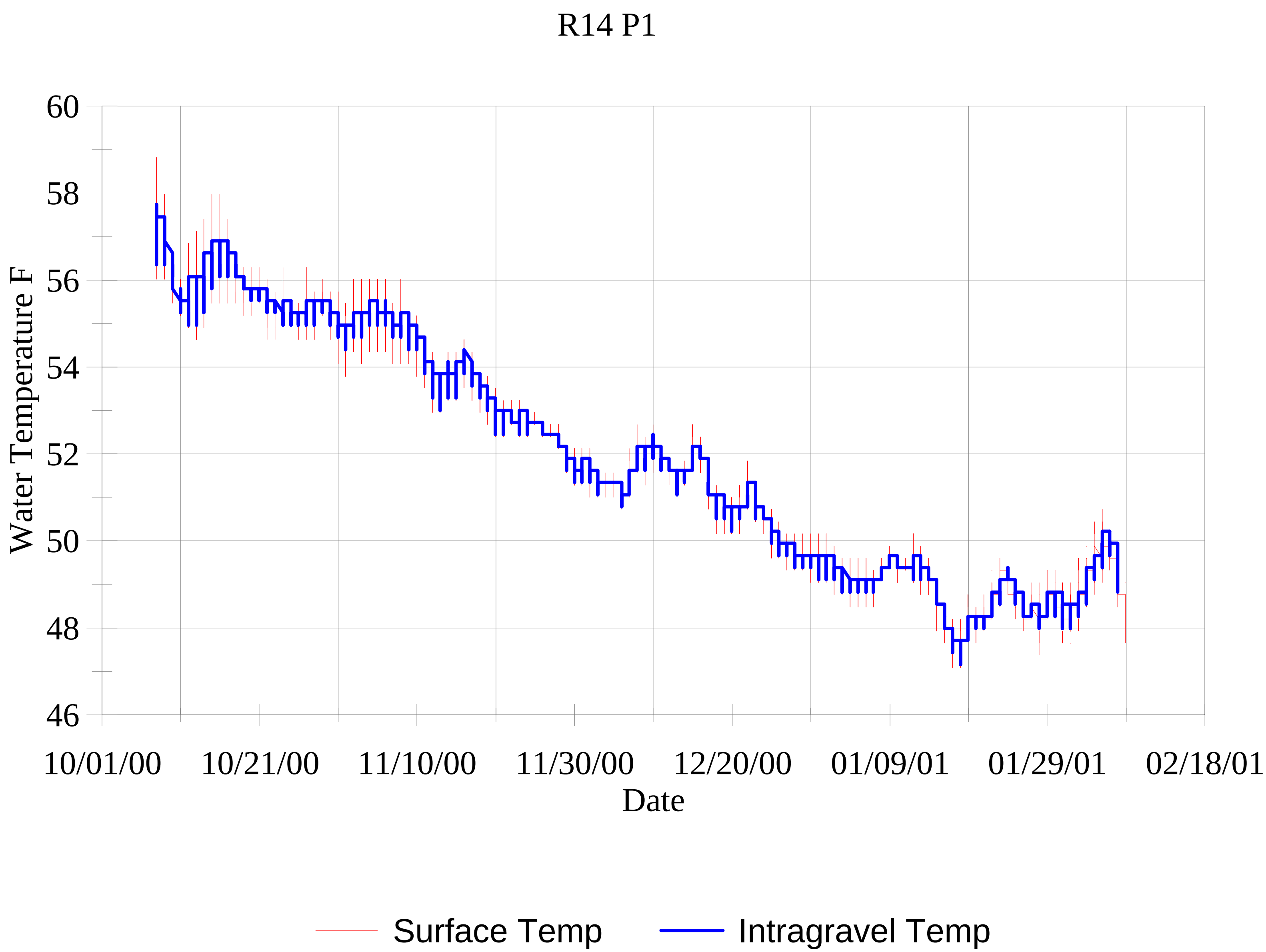

R1 P1
58
56
54
52
50
48
46
Water Temperature F
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp



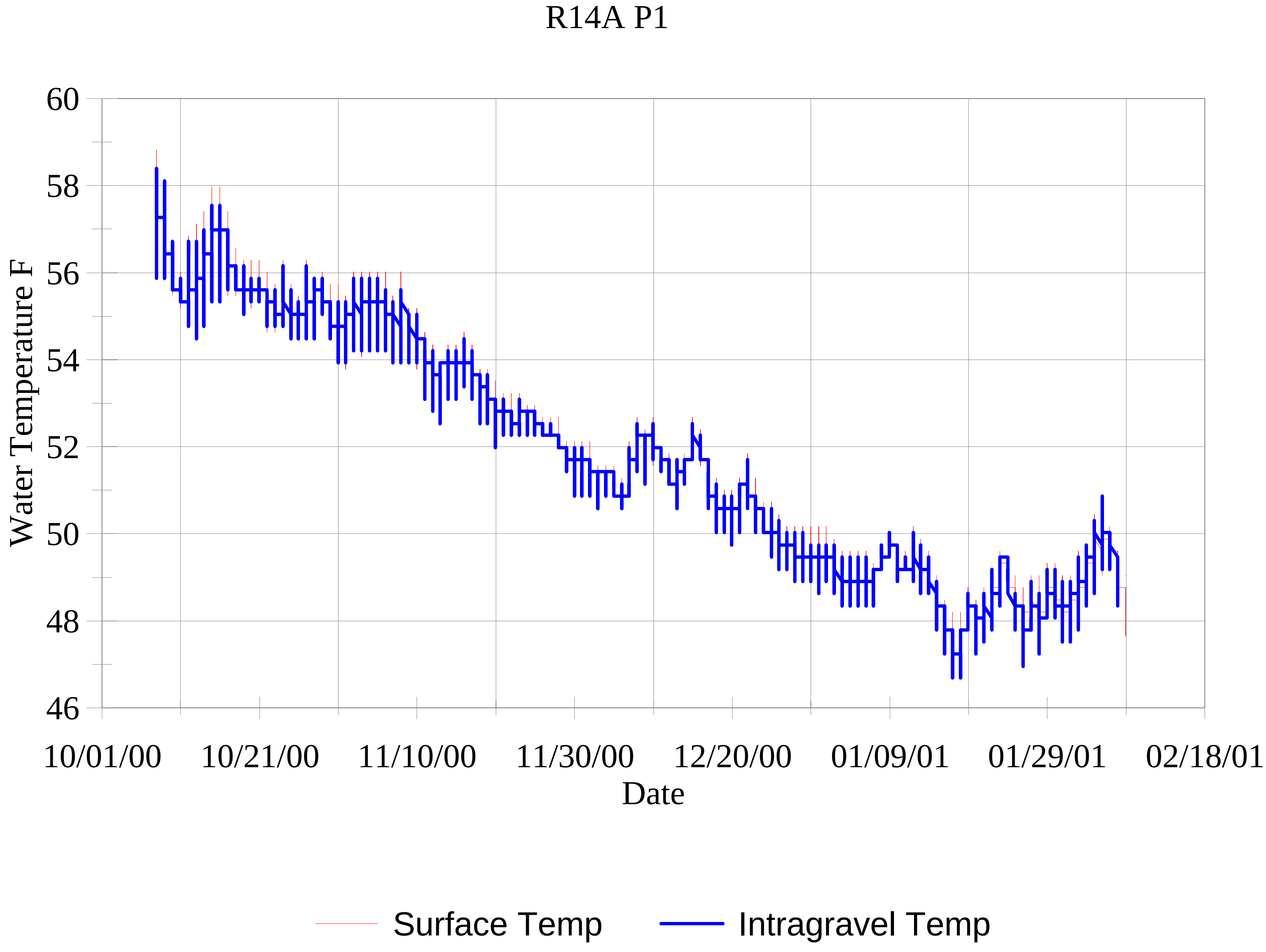
R1 P4
Water Temperature F
58
56
54
52
50
48
46
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp

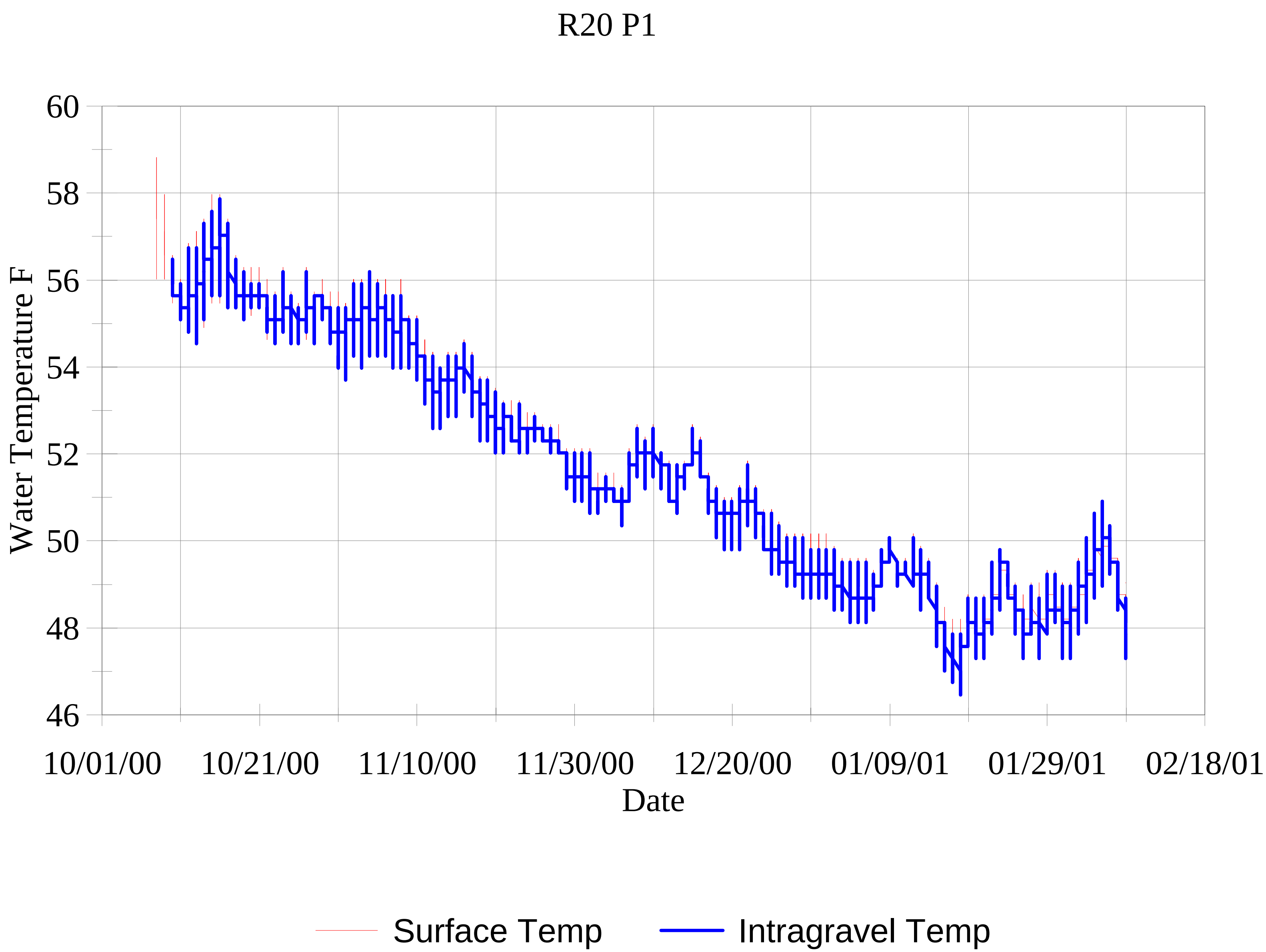


R5 P1
Water Temperature F
58
56
54
52
50
48
46
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp

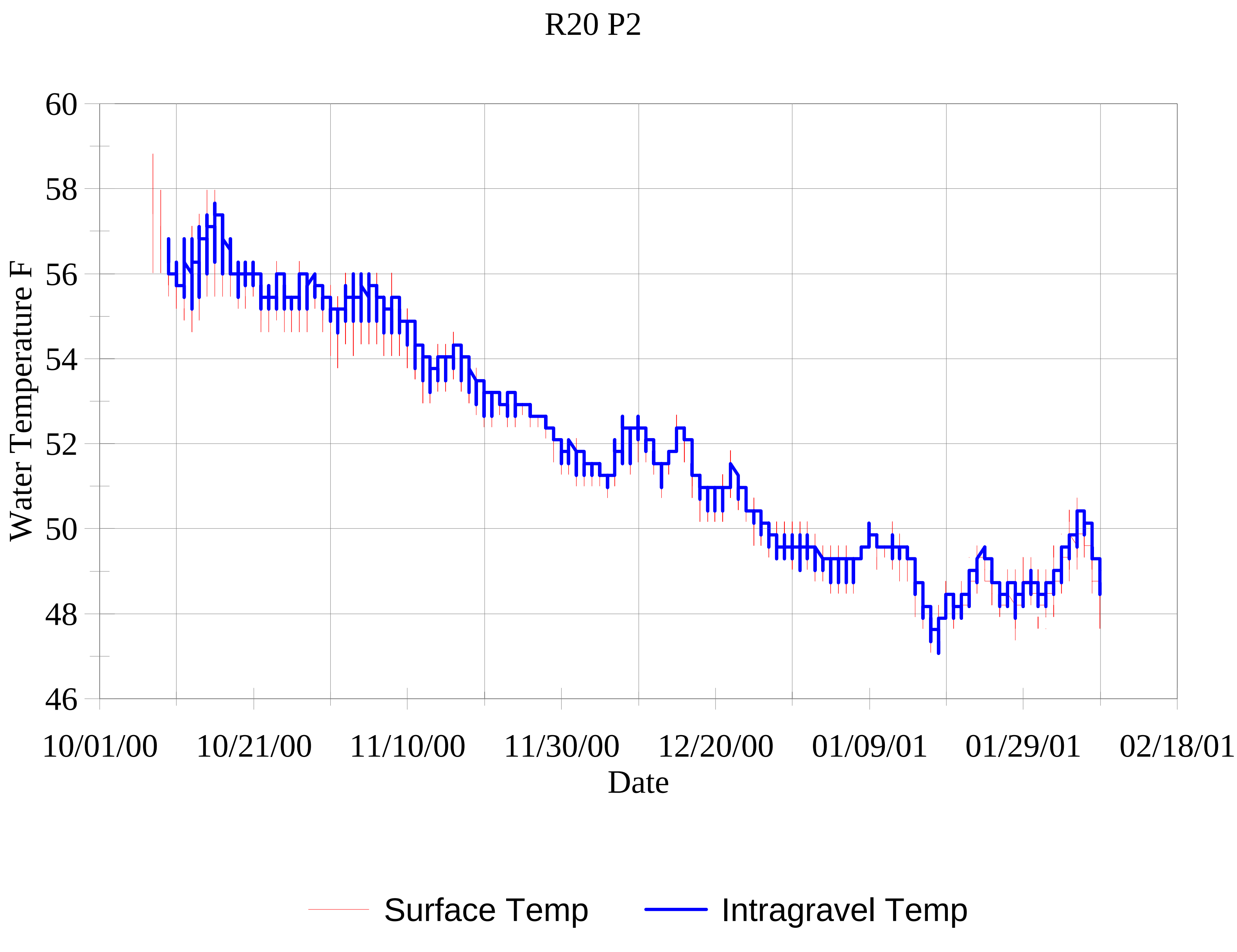


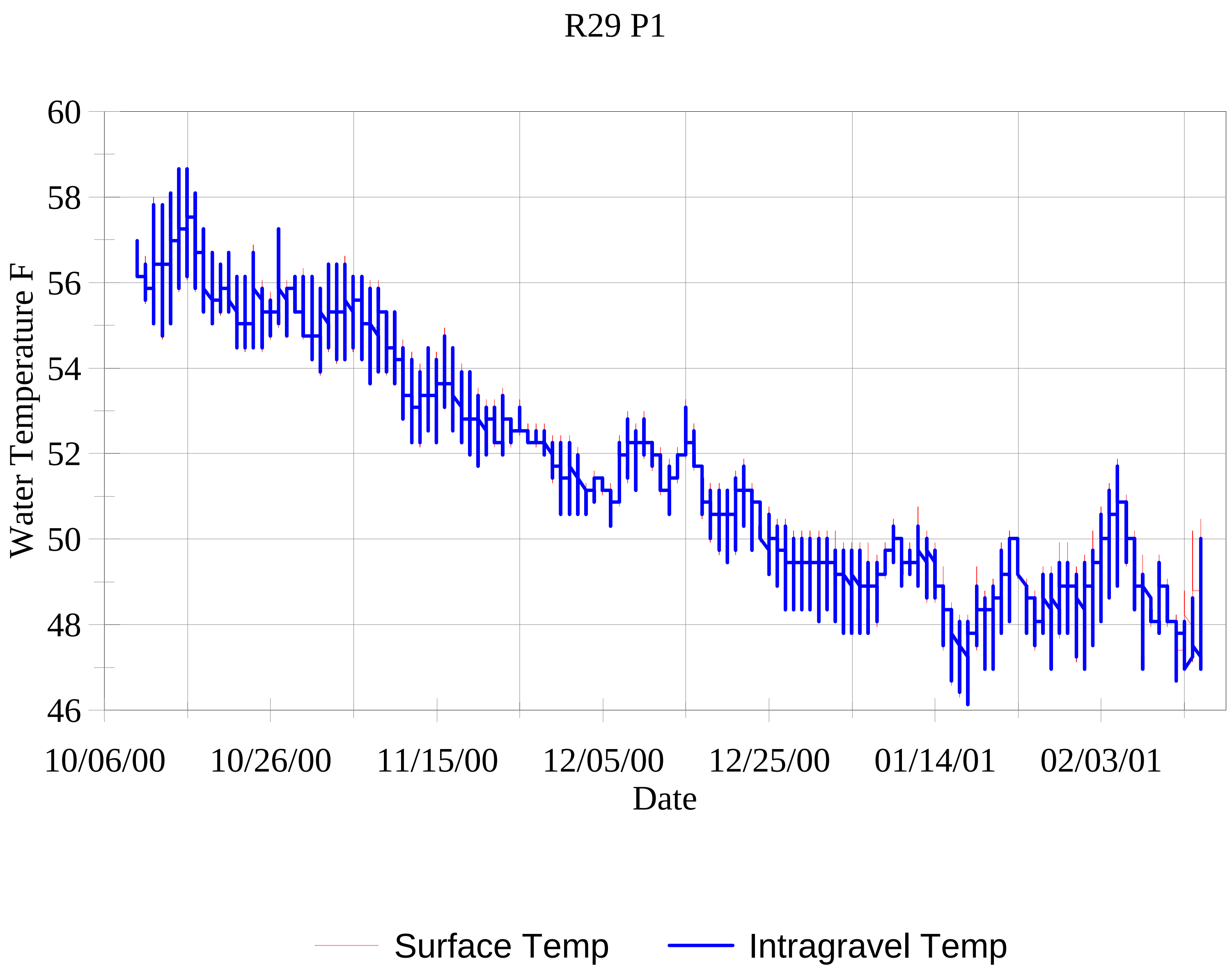
R14 P1
Water Temperature F
60
58
56
54
52
50
48
46
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp


R14A P1
Water Temperature F
60
58
56
54
52
50
48
46
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp

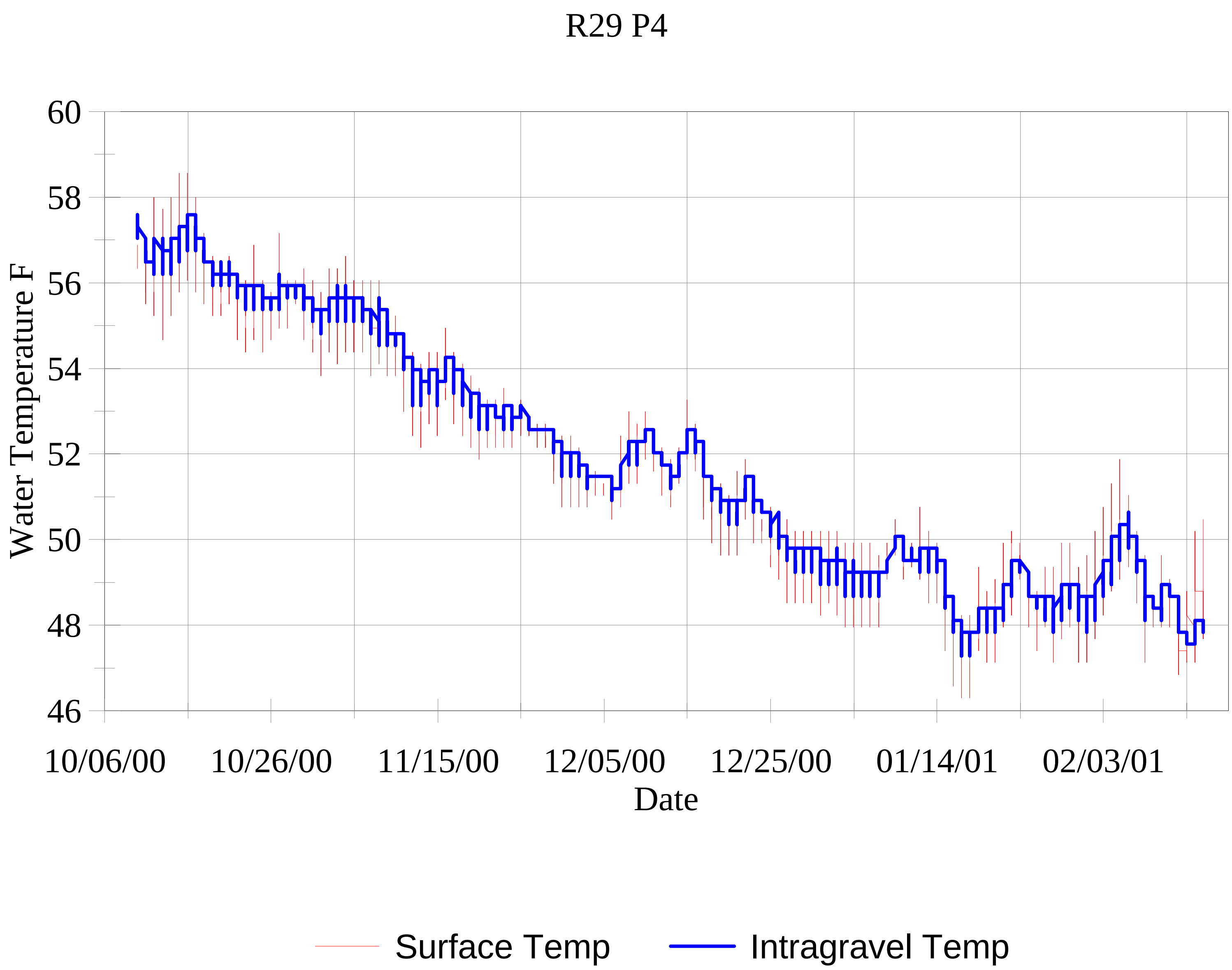


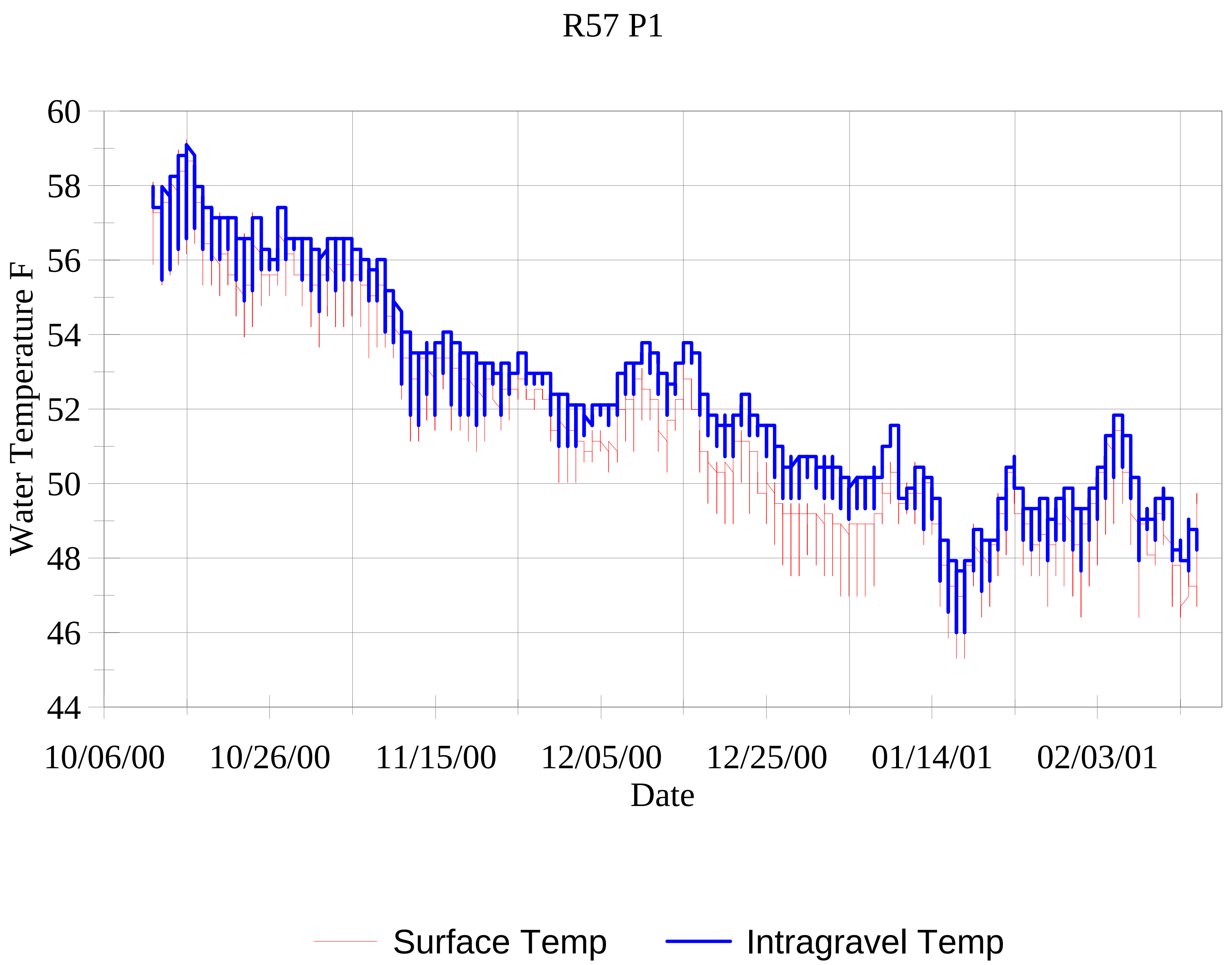
R20 P1
Water Temperature F
60
58
56
54
52
50
48
46
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp


R20 P2
60
58
56
54
52
50
48
46
Water Temperature F
10/01/00
10/21/00
11/10/00
11/30/00
12/20/00
01/09/01
01/29/01
02/18/01
Date
Surface Temp
Intragravel Temp



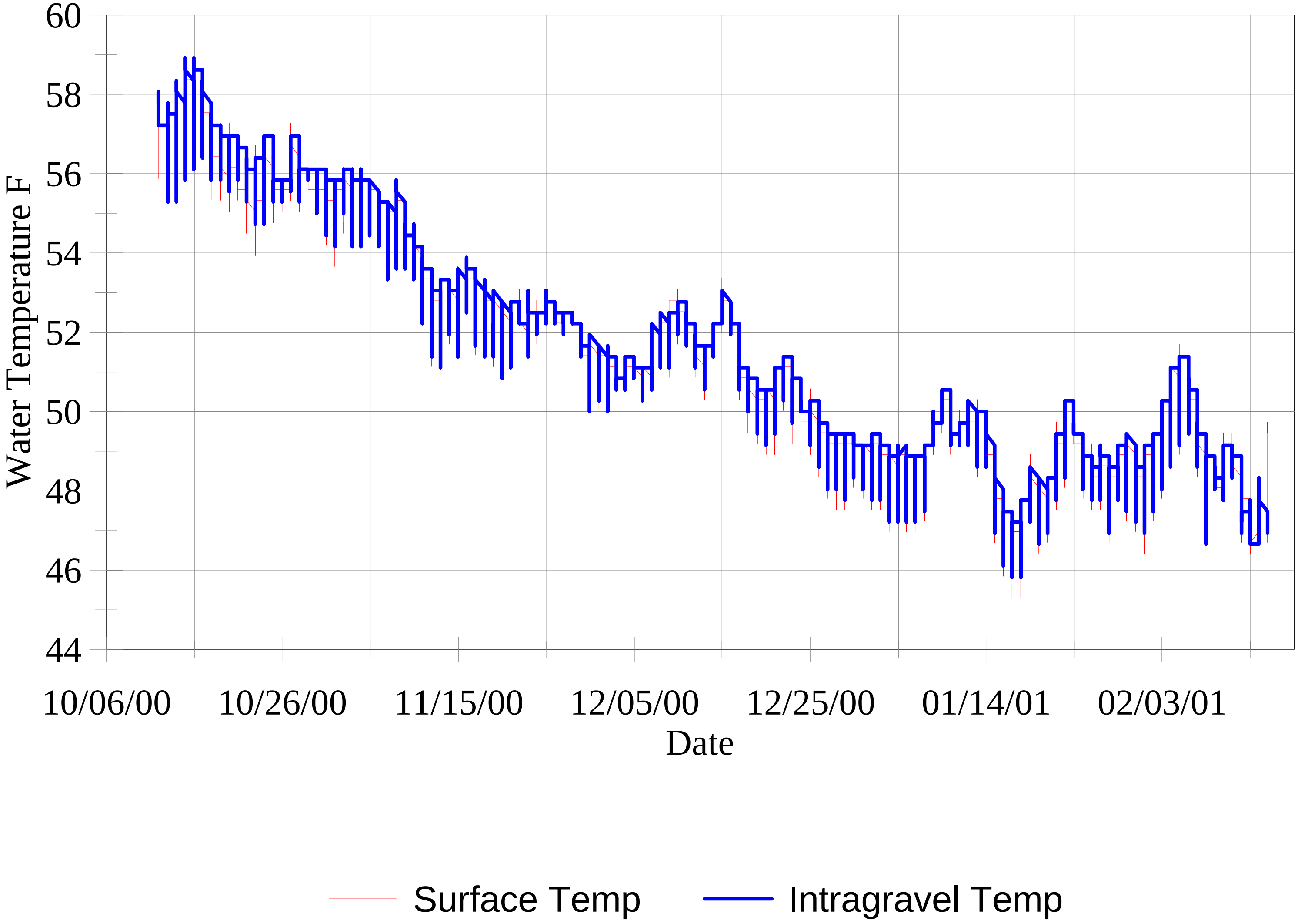
R29 P1
Water Temperature F
60
58
56
54
52
50
48
46
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp


R29 P4
Water Temperature F
60
58
56
54
52
50
48
46
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

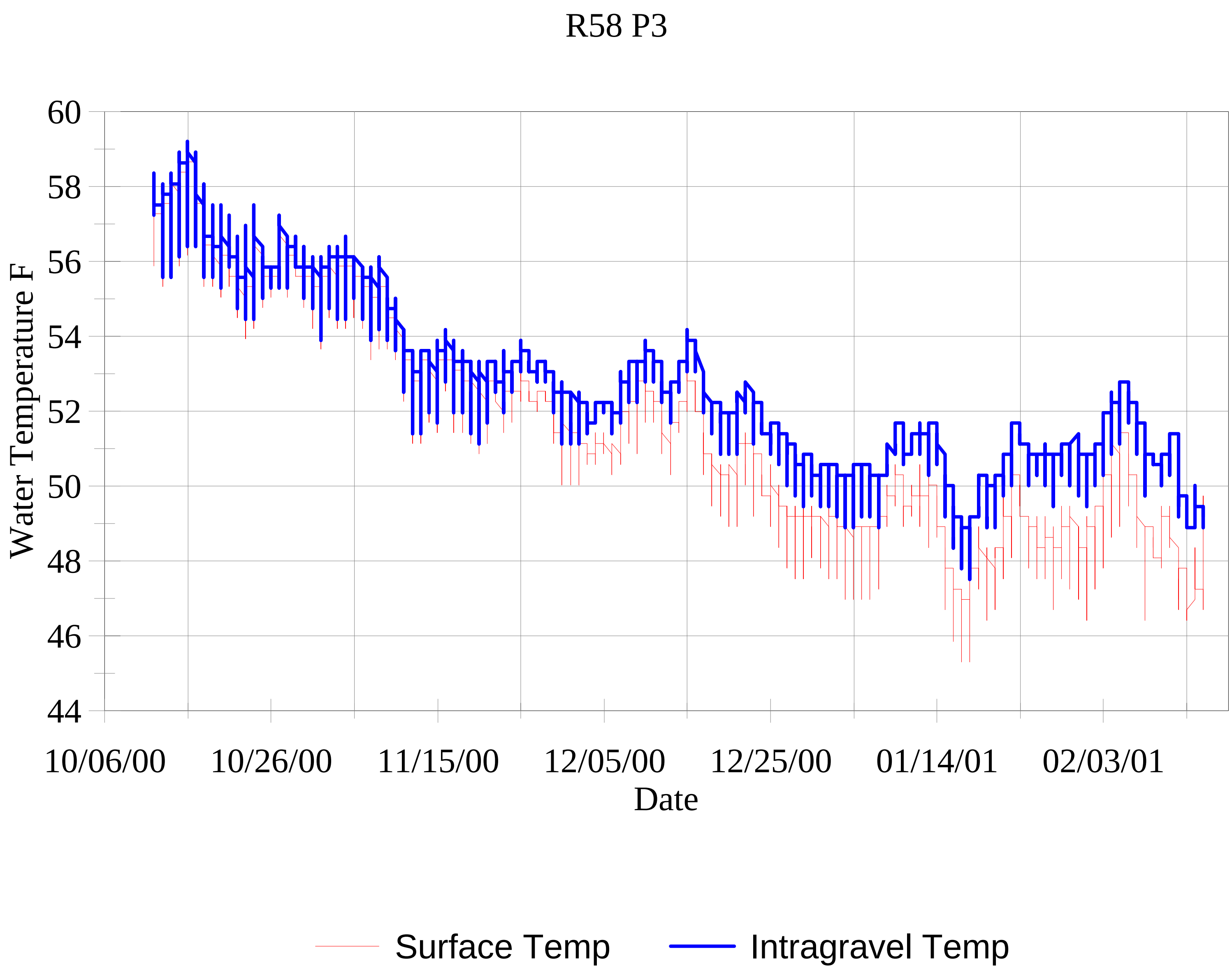


R57 P1
Water Temperature F
60
58
56
54
52
50
48
46
44
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

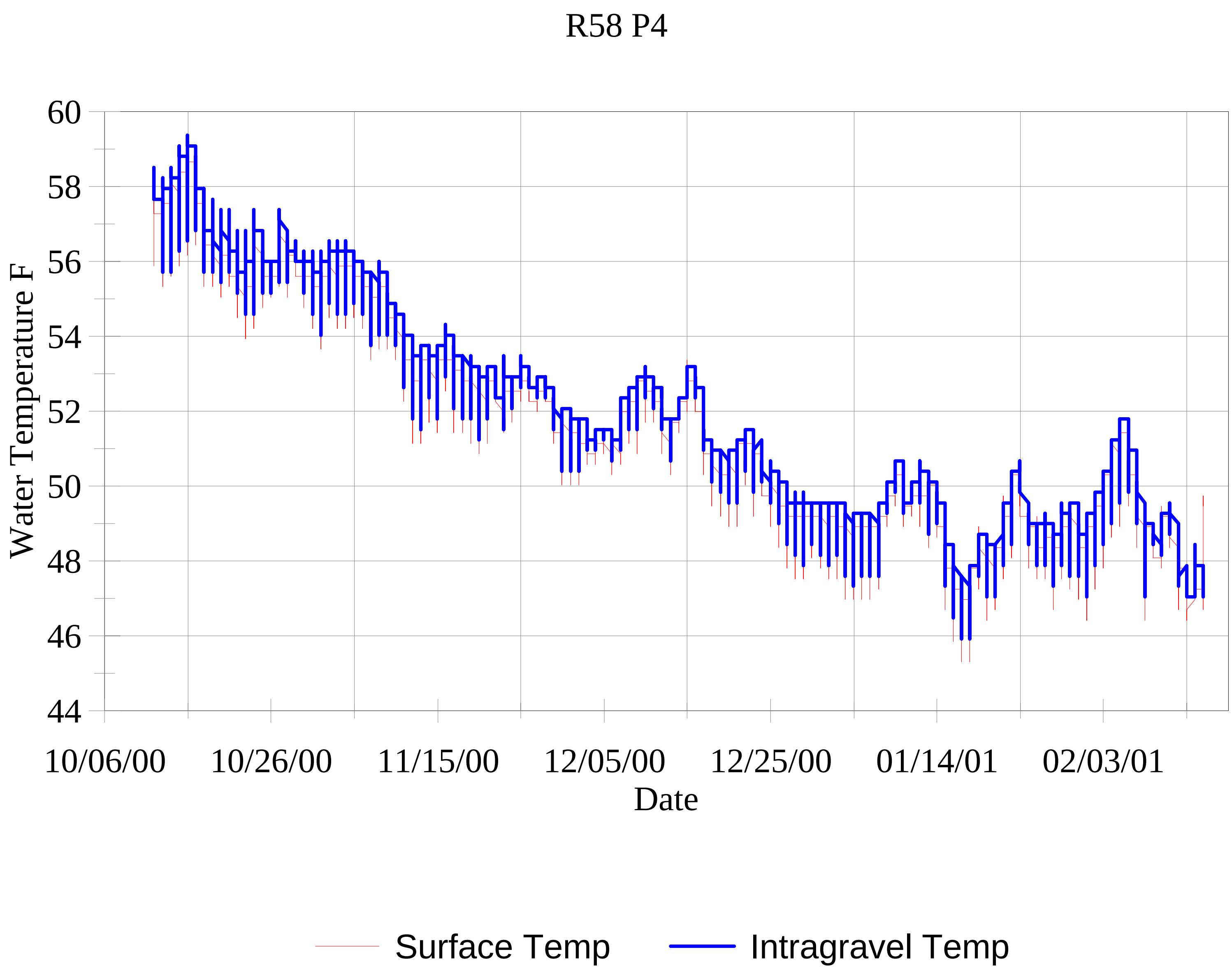
R57 P2



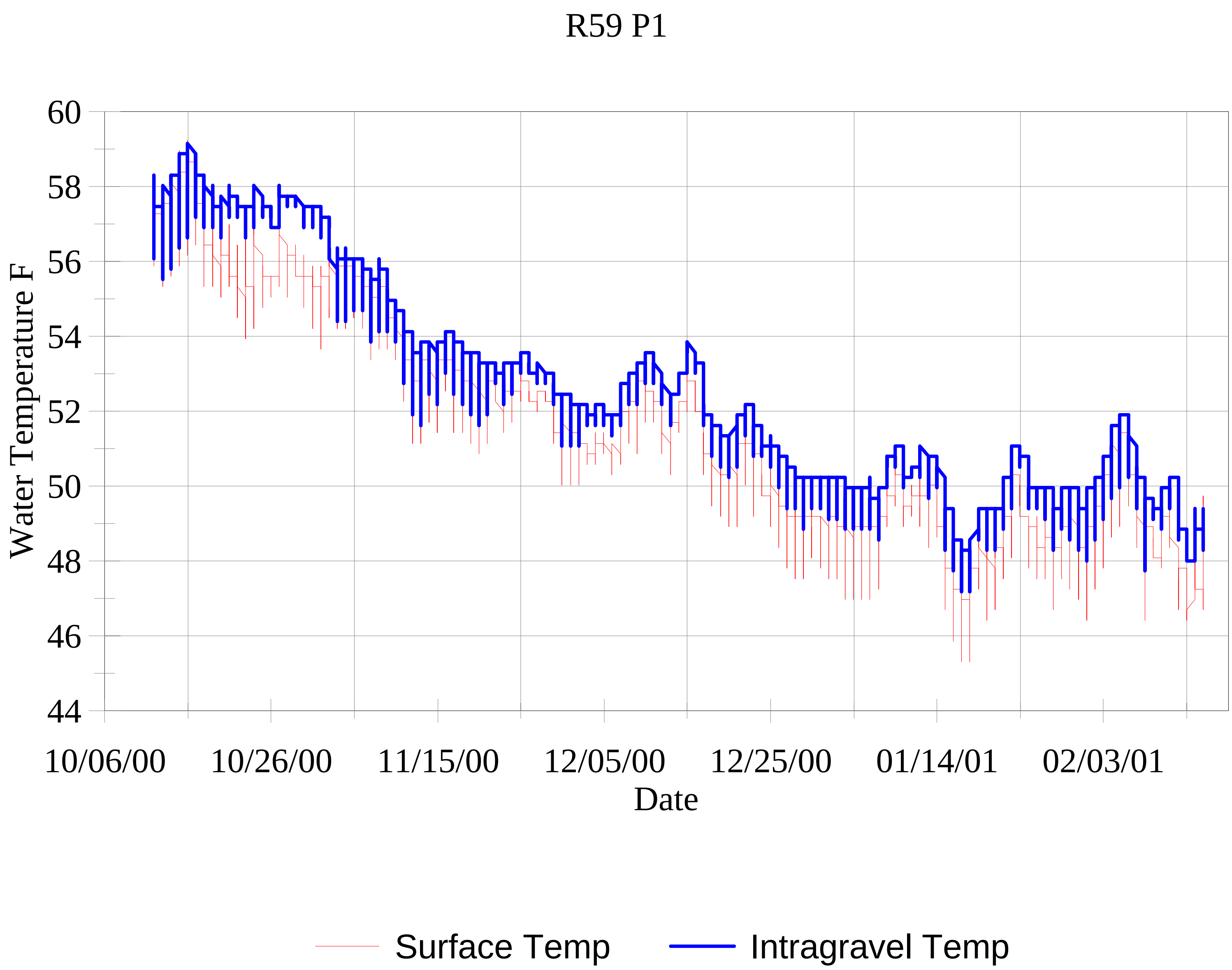
Water Temperature F
60
58
56
54
52
50
48
46
44
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

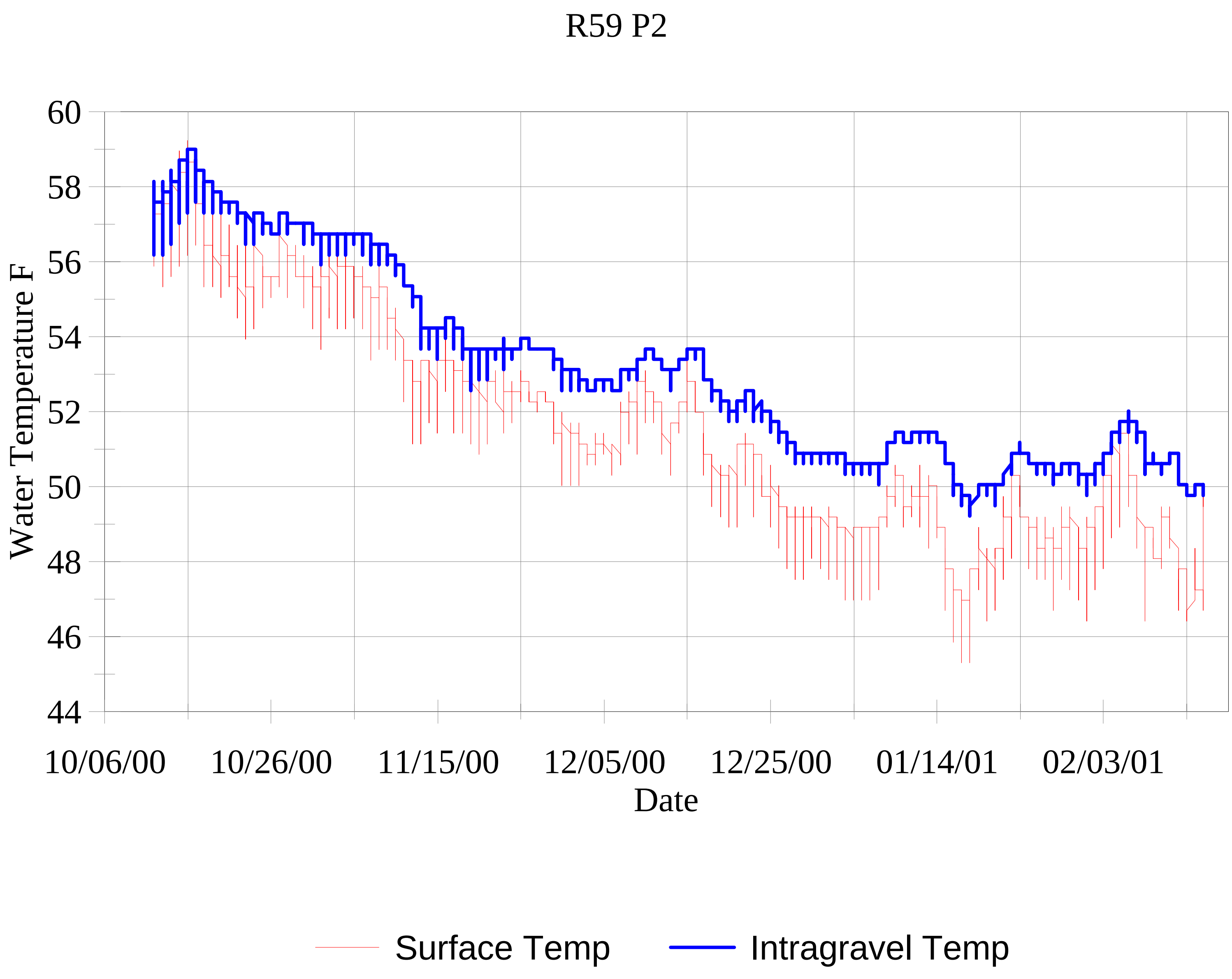


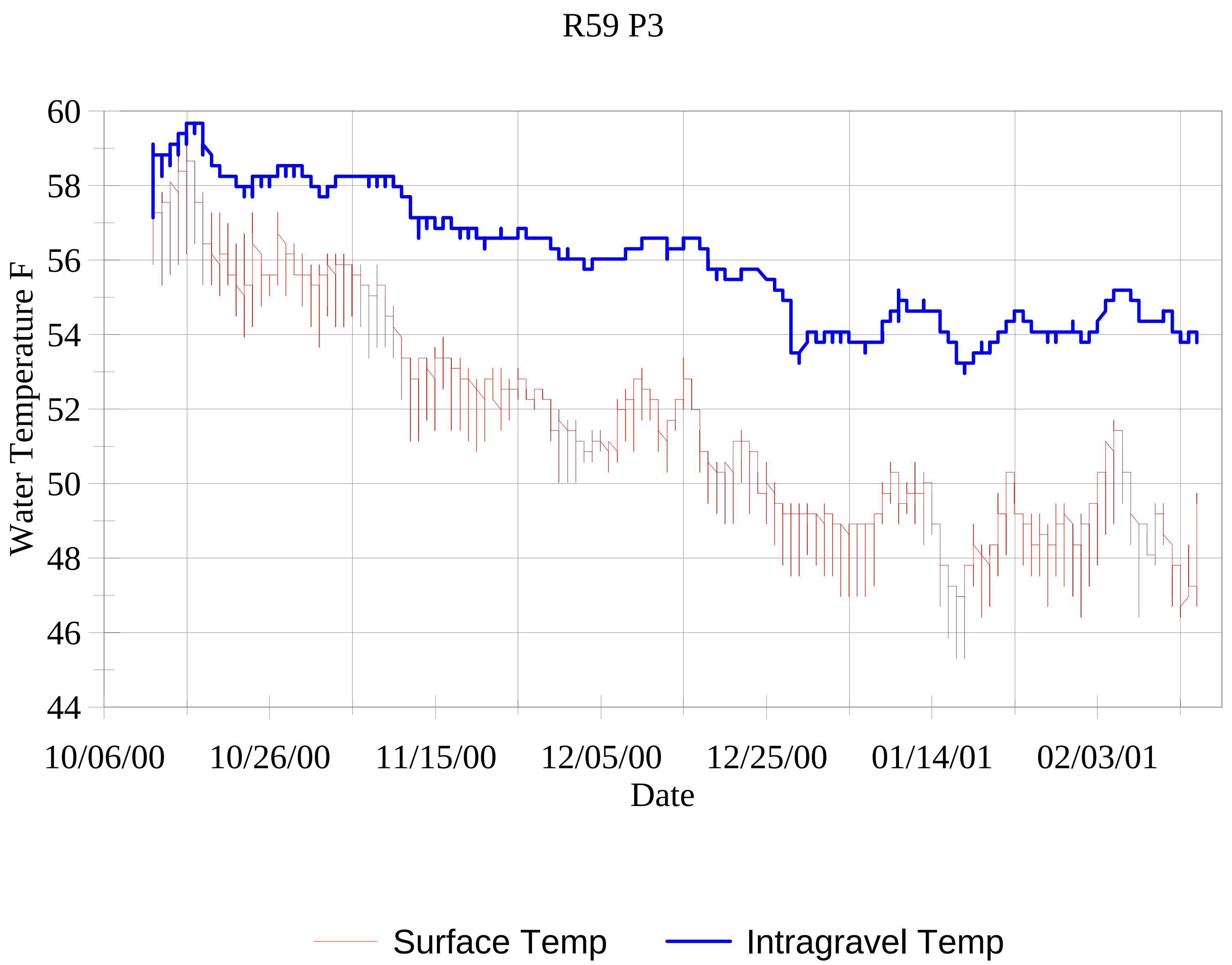
R58 P3
60
58
56
54
52
50
48
46
44
Water Temperature F
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp



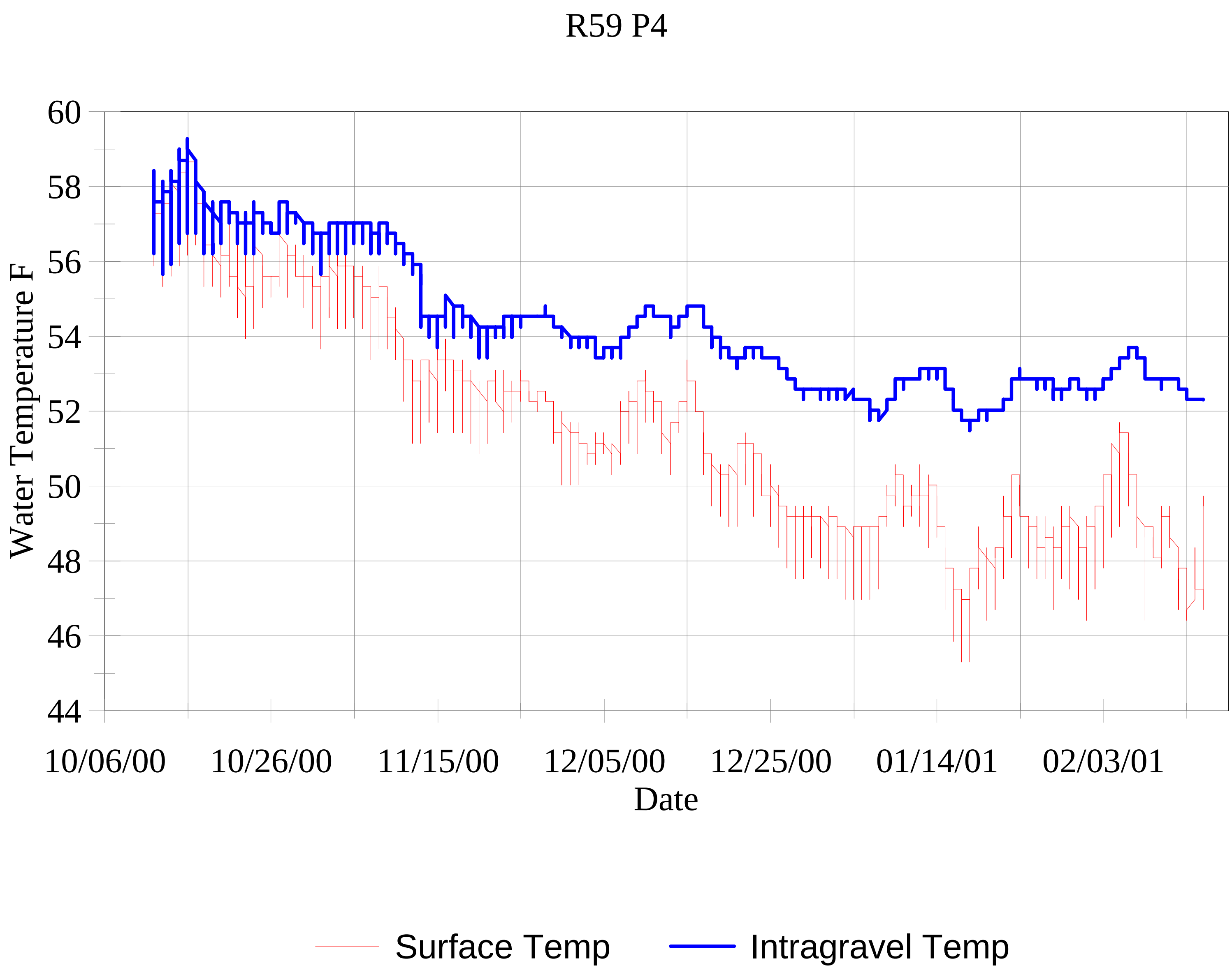
R58 P4
Water Temperature F
60
58
56
54
52
50
48
46
44
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

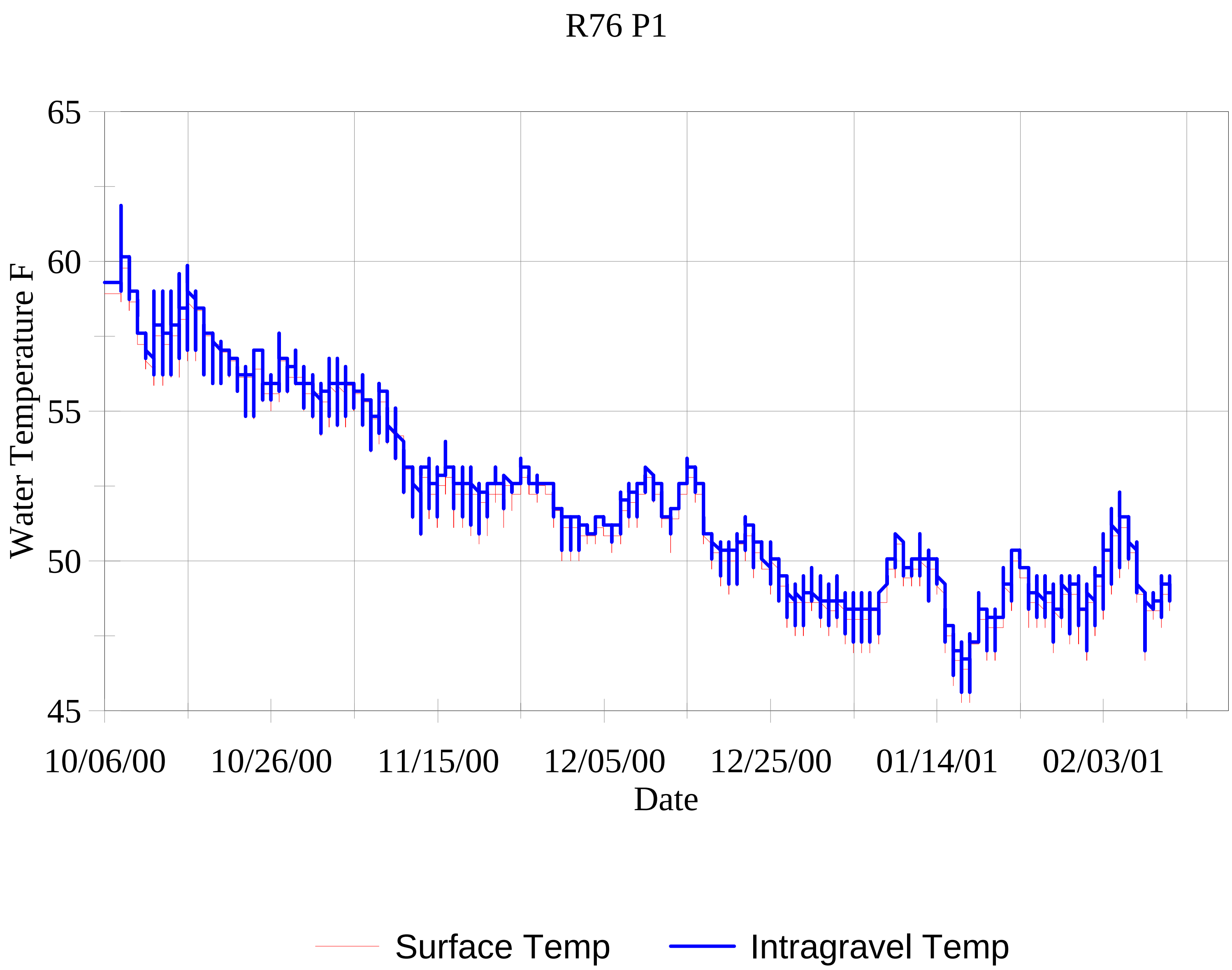

R59 P1
Water Temperature F
60
58
56
54
52
50
48
46
44
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

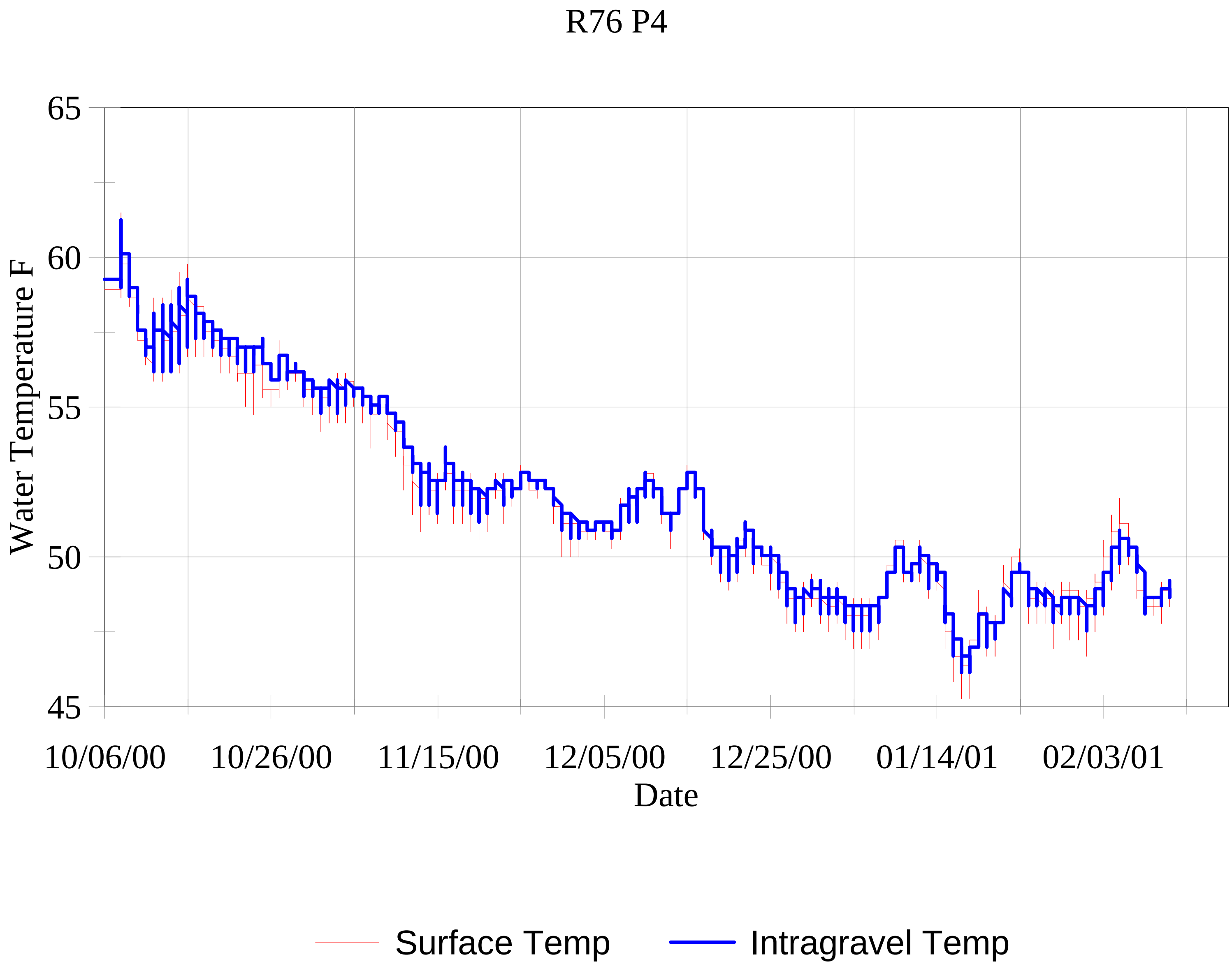

R59 P2
Water Temperature F
60
58
56
54
52
50
48
46
44
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

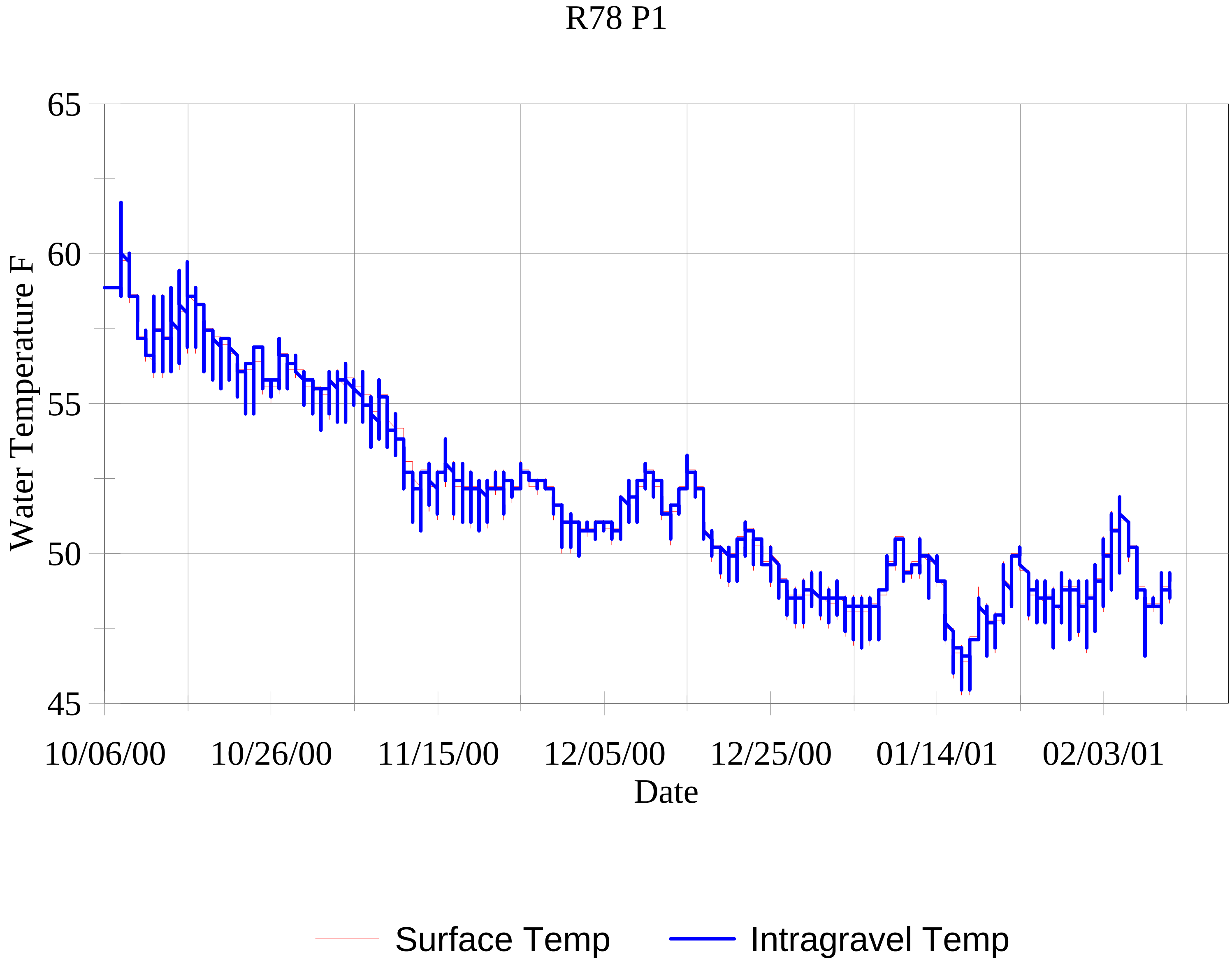


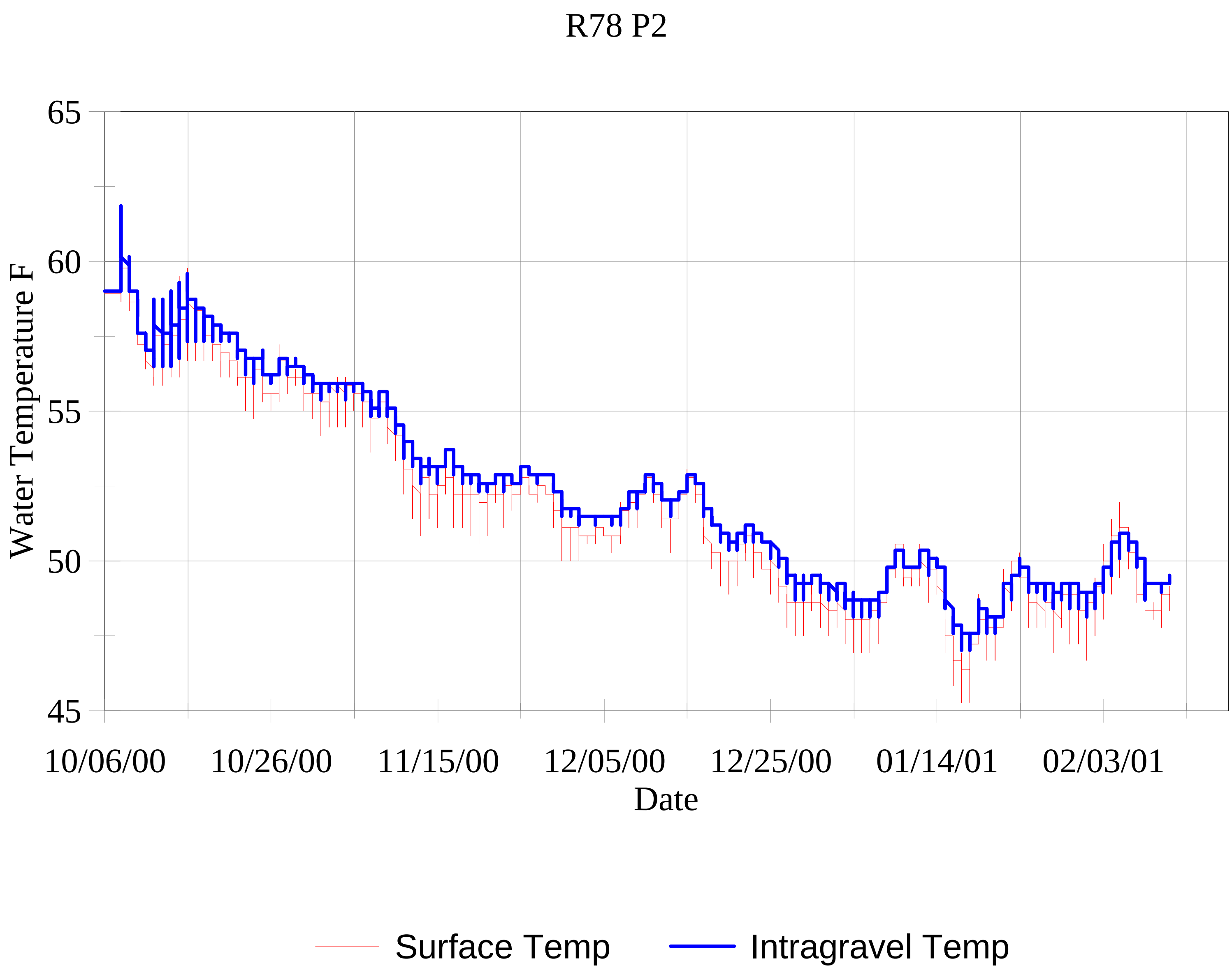
R59 P3
60
58
56
54
52
50
48
46
44
Water Temperature F
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp


R59 P4
60
58
56
54
52
50
48
46
44
Water Temperature F
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

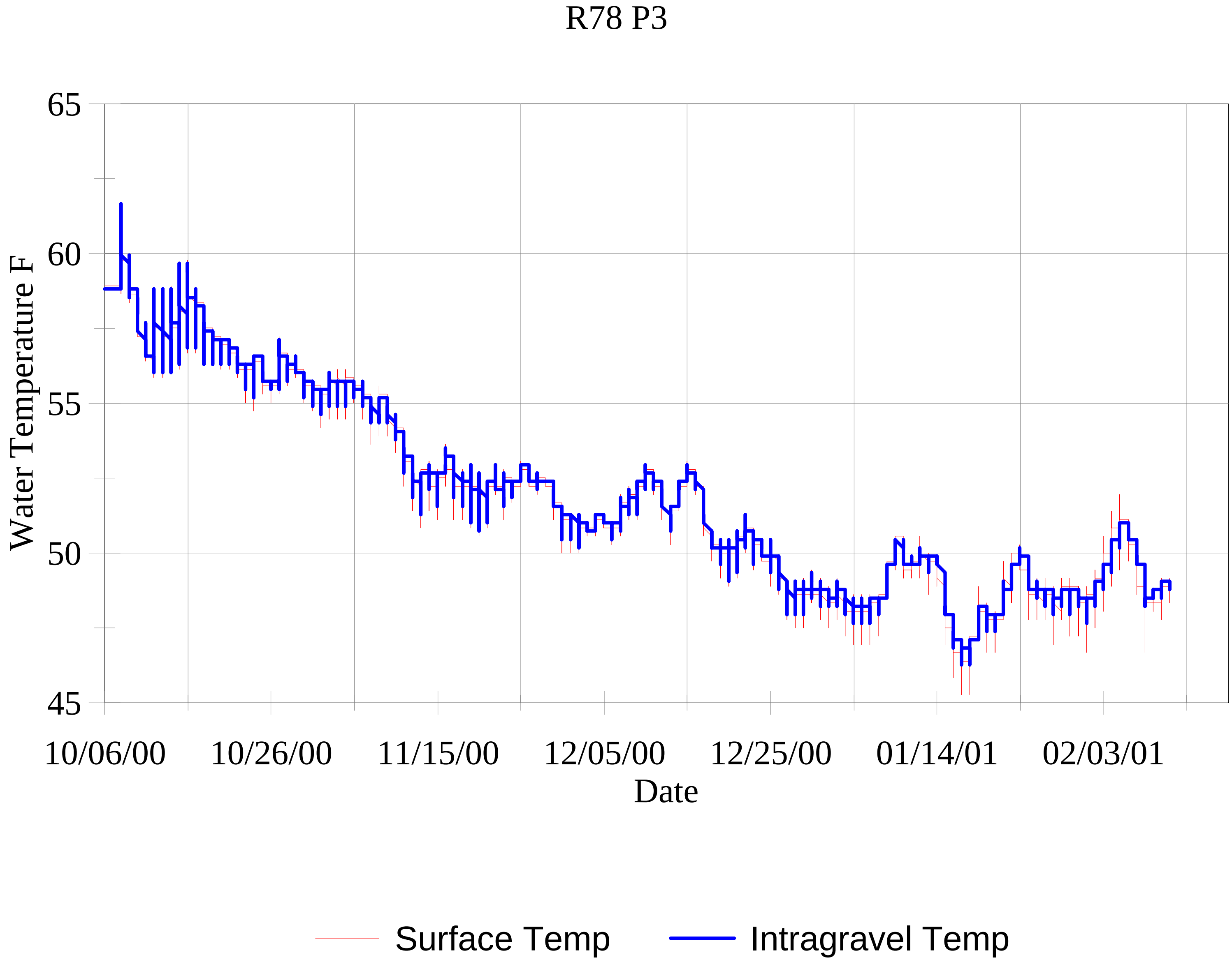

R76 P1
Water Temperature F
65
60
55
50
45
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp


R76 P4
Water Temperature F
65
60
55
50
45
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp

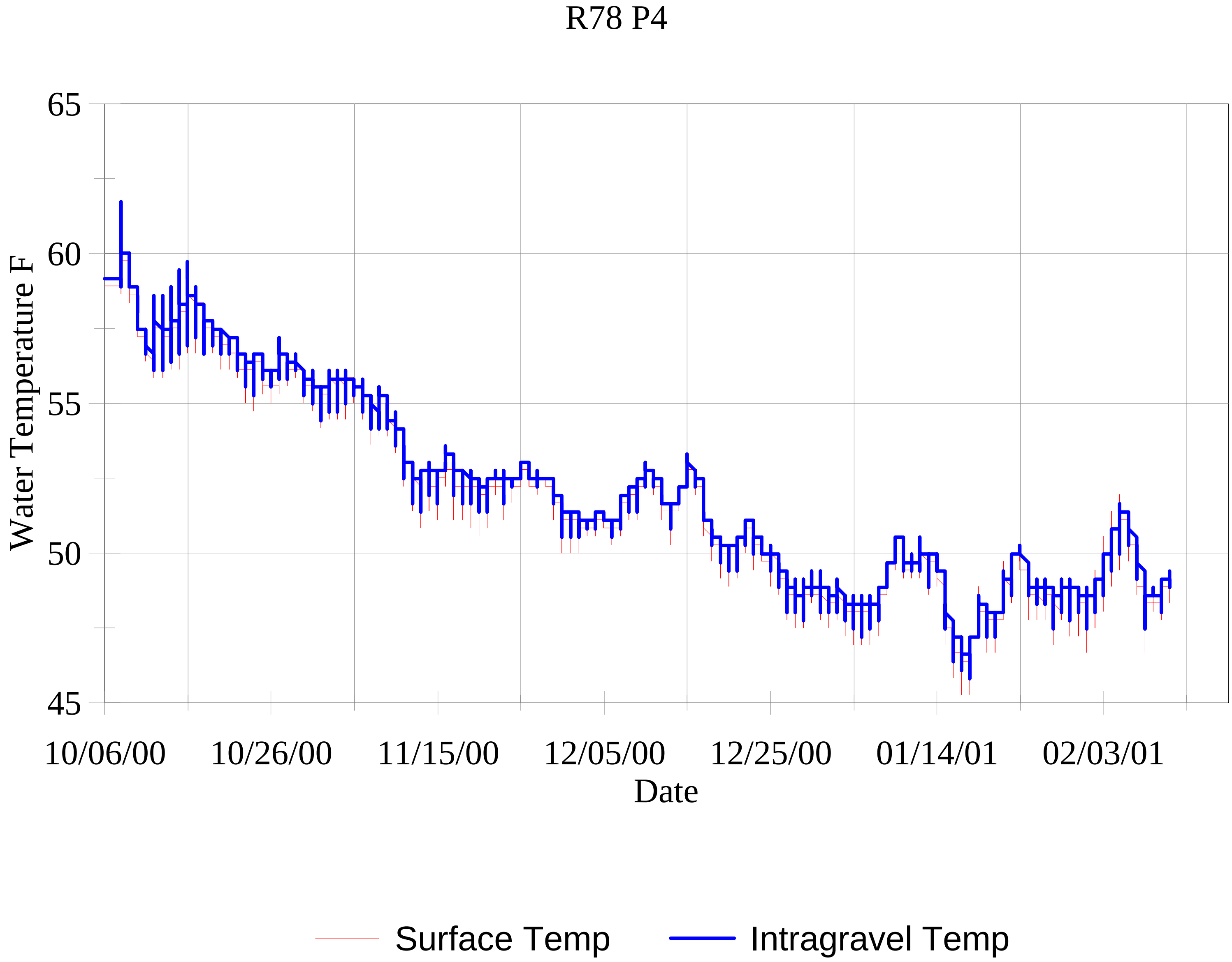

R78 P1
Water Temperature F
65
60
55
50
45
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp



R78 P2
65
60
55
50
45
Water Temperature F
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp



R78 P3
65
60
55
50
45
Water Temperature F
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp



R78 P4
Water Temperature F
65
60
55
50
45
10/06/00
10/26/00
11/15/00
12/05/00
12/25/00
01/14/01
02/03/01
Date
Surface Temp
Intragravel Temp